The Chemical Constraints on Creation: Natural Theology and Narrative Resonance

The 2010 Winifred E. Weter Faculty Award Lecture
Seattle Pacific University
February 2, 2010

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Department of Chemistry and Biochemistry

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Engaging the culture, changing the world.

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O Sapientia, quae ex ore Altissimi prodiisti,
attingens a fine usque ad finem,
fortiter suaviterque disponens omnia:
veni ad docendum nos viam prudentiae.[1]

[1] English translation: "O Wisdom, coming forth from the mouth of the Most High, reaching from one end to the other, mightily and sweetly ordering all things: Come and teach us the way of prudence." From traditional "O Antiphons" service.

Dedication

To Laurie Lynn Haugo McFarland

(for showing me how to listen and tune)

and

To George Scott Becker

(for showing me how to read the story)

Thanks

To Rick Steele and Cara Wall-Scheffler

(for critical readings and invaluable advice)

and

To Anna Miller and Tracy Norlen

(for organizing and getting the word out)

And

To Bruce Congdon

(for encouraging the trip to the conference that led to this lecture)

and

To my colleagues at SPU, in chemistry, in biology, and in all other disciplines

(for living as a truly ecumenical community of scholars)

Order of Program

Introduction: Tuning to the Universe

The New Natural Theology

Song One: From Nothing to Stars
starring “Math”

Song Two: From Stars to Heavy Atoms
starring “Entropy”

Song Three: From Heavy Atoms to Earth
starring “Gravity”

Song Four: From Rock to Sea and Sky
starring “Water”

Song Five: From Sea and Sky to Sulfur
starring “Bubbles”

Song Six: From Sulfur to Oxygen
starring “Photosynthesis”

Song Seven: From Oxygen to Humans
starring “The Brain”

What the Chemical Songs Mean

Tuning Two Stories

Conclusion: Reading the Music

Introduction: Tuning to the Universe

In the beginning, there was music. At creation "the morning stars sang together, and all the sons of God shouted for joy." (Job 38:7) Richard Wagner starts the Ring Cycle with the slow, rolling E-flat chord of creation.[2] C.S. Lewis has Aslan sing into the darkness and the stars join in harmony,[3] resonating with Tolkien's creation, in which "…the music and the echo of the music went out into the Void, and it was not void."[4] In each story, creation is a simple theme that builds in harmony and fugue to beautiful complexity. These stories resonate with the truth that creation examined closely seems tunefully ordered. As Einstein famously said, "The most incomprehensible thing about the world is that *it is at all comprehensible*."

Scientists are called to comprehend, to pay close attention to creation, so to read it like a sheet of music. William Herschel was a *musician* who applied his talents to build *scientific* instruments to sweep the skies – he had to "tune" his telescopes like musical instruments to see stars clearly. Biographer Richard Holmes wrote that "[Herschel] could read the night sky like a skilled musician sight-reading a musical score. … The astronomer had to learn to see, and with practice (as with a musical instrument) he could grow more skilful."[5] One night Herschel noticed a faint comet without a tail, and soon realized this was a seventh planet, Uranus. This musician and his instrument expanded the music of the spheres.

Moving from telescopes to microscopes, close attention to life reveals that every cell has the same chemical DNA, written with the same four nucleobases, using the same code to make proteins from the same 20 amino acids – the same even for dinosaurs![6] DNA is linear and is read sequentially like music. The lowest bacterium can read human "sheet music": if human DNA is a "tune" then bacteria can read that DNA and "play" that tune to make human proteins.[7] In my laboratory we use this technology. This is also how Michael Crichton proposed making dinosaurs: by placing dinosaur DNA in current reptiles to populate *Jurassic Park*.[8] (Research is not usually that successful.)

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[2] Wagner, R. (1869). *Das Rheingold*, first five minutes.

[3] Lewis, C.S. (1955). *The Magician's Nephew*.

[4] "Then the voices of the Ainur, like unto harps and lutes, and pipes and trumpets, and viols and organs, and like unto countless choirs singing with words, began to fashion the theme of Iluvatar to a great music … ." (Tolkien, J.R.R. (1977) *The Silmarillion*. p. 3 of 2004 Houghton-Mifflin illustrated ed.)

[5] Holmes, R. (2008). *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science*. Pantheon Books (Random House), p. 115-6.

[6] Schweitzer, M.H. *et al.* (2009). "Biomolecular Characterization and Protein Sequences of the Campanian Hadrosaur B. Canadensis." *Science* 324, 626.

[7] These proteins can be put back in the human body and returned to the human "symphony."

[8] Crichton, M. (1990). *Jurassic Park.* Knopf.

Zoom in further to the atoms that make cells. Paying close attention to chemistry reveals fewer than 100 elements are organized by the periodic table – most of which are not even useful for life.[9] For example, carbon forms four bonds, and is used in the complex shapes of DNA and proteins. Silicon also forms four bonds, but doesn't support life at Earth temperatures because it forms silicate glass. Silicon is heavier than carbon, so silicon oxide sticks to itself too much.[10] Like music itself, life requires flow, from ocean current to blood circulation, and silicon chains cannot flow.[11] Likewise, some elements are too heavy to be abundant, some are too highly charged to form flowing complexes (including this entire row of highly charged +3 elements),[12] some don't dissolve in seawater and some just plain don't do anything. Only about 20 building blocks are left behind to be used by life. By paying close attention to geochemistry, we can read the music of the ancient earth and can figure out which elements were "flowing" in ancient oceans. Elemental availabilities shaped how life did chemistry, or, which chemical "music" it could play.

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[9] Williams, R.J.P.; and J.J.R. Frausto da Silva. (2005). *The Chemistry of Evolution: The Development of our Ecosystem.* Elsevier Science: p.37. **Hereafter abbreviated as "CoE" in footnotes.**

[10] "For example, it is not possible to base stable linear polymers on sulfur or silicon polymers, and notice the much greater abundance of H, C, N, and O over S and P." [CoE p.142.]

[11] Quoted from *What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York p. 41: " "A living body," wrote Alan Watts, "is not a fixed thing but a flowing event." Watts, the Anglo-American popularizer of eastern philosophy, drew from science, as well, in his quest for the meaning of life. He likened life to "a flame or a whirlpool": "the shape alone is stable. The substance is a stream of energy going in at one end and out at the other. Life's purpose to maintain and perpetuate itself is understandable as a physiochemical phenomenon studied by the science of thermodynamics. We are temporarily identifiable wiggles in a stream that enters us in the form of light, heat, air, water, milk … It goes out as gas and excrement – and also as semen, babies, talk, politics, war, poetry, and music."

Yet there is something constant to this ripple that is "me," my heart from which evil can come: 'So He said to them, "Are you thus without understanding also? Do you not perceive that whatever enters a man from outside cannot defile him, because it does not enter his heart but his stomach, and is eliminated, *thus* purifying all foods?" And He said, "What comes out of a man, that defiles a man. For from within, out of the heart of men, proceed evil thoughts, adulteries, fornications, murders, thefts, covetousness, wickedness, deceit, lewdness, an evil eye, blasphemy, pride, foolishness. All these evil things come from within and defile a man."' (Mark 7: 18-23 NKJV)

[12] This is mostly from precipitation as insoluble hydroxides at pH 7. See CoE p.17. Also, that groups 3, 4, 13 and 14 are not used in life, see CoE p.134. For a hypothesis of why *both* Al and Si are not used by life, see Exley, C. (2009). "Darwin, natural selection and the biological essentiality of aluminum and silicon." *Trends Biochem. Sci.* 34 (12), 589-93.

The New Natural Theology

Elemental availabilities tell another creation story after Job's, Wagner's, Lewis', and Tolkien's; in its own way, a *musical* story. Much of the coming story is from a remarkable book, *The Chemistry of Evolution*, by bioinorganic chemists R.J.P. Williams and J.J.R. Frausto da Silva.[13] We will put this story in the light of the scriptural story of creation, that you may know both stories in a new way.[14]

To align both stories I will use tools of natural theology. This is not the natural theology of William Paley's toe-stubbing watch, but it is updated and perhaps chastened. As Alister McGrath writes:[15]

It seeks resonance of faith with nature, not proof of faith from nature. It does not demand a Creator, but it does make sense with one. It is an empirical fit, which Ian Ramsey said "works more like the fitting of a boot or a shoe than like the 'yes' or 'no' of a roll call."[16] Musically, it is like tuning two instruments together. This natural theology is not atomizable proof but is more like verbal testimony.[17]

It focuses on the big picture of nature, not the gaps in our understanding, seeking out "the overall patterns of ordering which are discerned within the universe,"[18] and so is inductive or abductive rather

[13] These two scientists have produced several other "seminal" works that have inspired scientists to think about bioinorganic chemistry in the context of natural selection (adjective quoted from Exley, C. (2009). "Darwin, natural selection and the biological essentiality of aluminum and silicon." *Trends Biochem. Sci.* 34 (12), 589-93.). Other chemical stories are of course possible. Several, including that of Williams and Frausto da Silva, are reviewed in Weber, B. (2007). "Emergence of Life." *Zygon,* 42 (4), 837-56.

[14] Science as story is a theme underlying several science writers' vocation. See for example, Olson, R. (2009). "Tell Me A Story of Science." *The Scientist*, 23 (10), 27.

[15] McGrath, A.E. (2008). *The Open Secret: A New Vision for Natural Theology.* Wiley-Blackwell.

[16] Ramsey, Ian (1964). *Models and Mystery*. Oxford University Press, p. 17. John Polkinghorne points out, "in the twentieth century after Kurt Godel, we have come to see that proof is a limited, and in some ways unsatisfactory, category. The new natural theology is no rival to science but seeks to complement it." [Polkinghorne, J. (2000). *Faith, Science, and Understanding*. Yale University Press, p. 61.]

[17] Asa Gray pointed out that design can never be proved by principle: "Evidence of design, I think you will allow, everywhere is drawn from the observation of adaptations and of results, and has really nothing to do with anything else, except where you can take the word for the will. And in that case you have not argument for design, but testimony. In Nature we have no testimony; but the argument is overwhelming." [Asa Gray (1860). "Design versus Necessity," *American Journal of Science and Arts* quoted by Bethany Sollereder, ASA 2009 lecture, "The Darwin-Gray Exchange." August 1, 2009, *www.asa3.org*.]

[18] McGrath, A.E. (2008). *The Open Secret: A New Vision for Natural Theology.* Wiley-Blackwell. P. 240.

than deductive. It identifies a tune within noise, as Michael Polanyi wrote.[19] If "Music is organized sound,"[20] then I see the same tuneful organization in the ordered columns of the periodic table and the chemical sequence of which elements were available when. Life depends on the periodic table, echoing what Rowan Williams calls "the most comprehensive 'fact' of all, the *dependent* condition of the universe and everything in it."[21]

Natural theology's characteristic alignment places two pieces of knowledge side by side. Scripture encourages alignment: Paul aligns the crucified Messiah with the music of the Psalms; Matthew aligns Jeremiah's prophecy with King Herod's tyranny. Tonight is a parallel experiment: align scripture with nature and see what happens. When two waves or images are aligned so that their shapes match, both add together and reinforce. In both musical and chemical terms, they *resonate*.

First we must independently interpret science and scripture, and *then* see which shapes align. Antoine Lavoisier said, "When we begin the study of any science, we are in the situation … similar to that of children … ."[22] We must also come as children to study Scripture. Only once we have read each story faithfully, can we align similar shapes or motifs. When singing in choir, I must listen closely, tuning my body to the tones and my mind to the text, repeated through practice, practice, practice. Only then can

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[19] To discern reality in data, Michael Polanyi said, "Think of the difference between a tune and a noise … To distinguish meaningful patterns from random aggregates is therefore to exercise our power for recognising reality." [Polanyi, M. (1967). "Science and Reality." *British Journal for the Philosophy of Science*, 18 (3), 177-96.]

[20] Composer Edgard Varese quoted by Levitin, D. (2006). *This is Your Brain on Music: The Science of a Human Obsession.* Plume Books, p.14.

[21] Williams, R. (2000). *Lost Icons: Reflections on Cultural Bereavement.* Morehouse*;* quoted by Stanley Hauerwas in *State of the University*. Stanley Hauerwas adds, "Look at the birds of the air and consider the lilies of the field and see the love that moves the sun and the stars." [Hauerwas, S. (2008). *The State of the University: Academic Knowledges and the Knowledge of God.* Wiley-Blackwell, p. 210.] By this definition, the Sermon on the Mount contains natural theology. G.K. Chesterton, speaking of this parable, indirectly offers an analysis of the characteristics of natural theology rightly done: "There is perhaps nothing so perfect in all language or literature as the use of these three degrees in the parable of the lilies of the field; in which he first seems to take one small flower in his hand and note its simplicity and even its impotence; then suddenly expands it in flamboyant colours into all the palaces and pavilions full of a great name in national legend and national glory; and then, by yet a third overturn, shrivels it to nothing once more with a gesture as if flinging it away. … Merely in a literary sense it would be more of a masterpiece than most of the masterpieces in libraries; yet it seems to have been uttered almost at random while a man might pull a flower. … There is nothing that really indicates a subtle and in the true sense a superior mind so much as this power of comparing a lower thing with a higher and yet that higher with a higher still; of thinking on three planes at once. … something that can only be called subtle and superior, something that is capable of long views and even of double meanings, …" [Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press p.333.]

[22] Holmes, R. (2008). *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science*. Pantheon Books (Random House), p. 248.

we achieve resonance. (Stanley Hauerwas would no doubt add that *practice* in community produces sound *doctrine* too!)[23]

It is crucial to interpret science and scripture independently and not to impose external structure prematurely. The book *Lies My Music Teacher Told Me*[24] describes how well-tempered piano tuning introduces small distortions that push *a capella* chords out of tune. When singing I must first shape my body to shape the sound and then I must tune to my neighbor, not to a piano, if our chords are to resonate. In the same way, scientific and theological instruments must be used accurately and independently *before* their conclusions are joined – and their conclusions should only be joined where the shapes match.

An example of how this works: Close attention to scripture shows that New Testament authors expect physical, bodily resurrection like what happened to Jesus, a new body somehow both continuous and discontinuous with the old.[25] Close attention to chemistry shows that when matter changes phases, say, from solid to liquid, it flows differently. If "life is flow," then maybe scripture aligns with chemistry here. Resurrection might be something like (but much more than) a phase change, a material difference like solid becoming liquid, or stones becoming suns.[26] This metaphor proves nothing, but aligns and overlaps, even reinforces, spheres of knowledge, working from the conviction that the creator of this creation is the same as the creator of new creation. Where the shapes of the two stories match, we can add them together, two become one, and they "resonate." (Don't put the cart before the horse: close reading of Philippians 3 will ***not*** produce phase change theory!)

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[23] Pun on "sound" entirely intentional. Hauerwas and Willimon write, for example, that "Joining our voices with others in the repetition of this prayer, we are reminded that being a Christian is too tough to go alone. This is public theology. We admit that we would never have known how to pray as a Christian had the church not reached out to us through baptism and taught us this prayer." [In (1996) *Lord, Teach Us: The Lord's Prayer and the Christian Life*. Abingdon, p. 17.]

[24] "Perhaps the impassioned love affair with tempered tuning, combined with the hardened crusts of the traditional concepts of scales, has distracted us from these basic truths of nature. Perhaps if we take another listen to how poorly our choirs sing, and how difficult it is to train the ears of our young musicians, we will reconsider our unswerving devotion to tempered-tuned scales." Eskelin, G. (1994). *Lies My Music Teacher Told Me*. Stage 3 Publishing (Woodland Hills, CA), p.77. Most of the "lies" are centered around this problem.

[25] See Wright, N.T. (2003). *The Resurrection of the Son of God.* Fortress Press, especially 1 Corinthians discussion in Chapter 7. The process of natural theology itself must start with a refutation of the Gnostic assumption that the physical and spiritual are complete opposites.

[26] Although God's action is infinitely above our understanding, we can use the world he has given us to interpret the words of scripture, and also works of art. It may be like Aslan thawing frozen stone statues with his breath in *The Lion, The Witch, and the Wardrobe*; this "phase change" seems an appropriate image of the resurrection.

So consider this somewhat more complex chemical reaction, a transition from nothing to humans with several intermediates:

nothing → stars →heavy atoms → Earth → sea/sky/hydrogen → sulfur → oxygen → humans

The reaction arrows are an imitation of chemical mechanisms but delineation into stages also implies a theological view of time as a drama[27] or music. Before this reaction is over, the universe will be built from numbers and light; the law of spreading out will bring the world together; a blessed planet will be born with an invisible guardian; life may emerge from soap and fool's gold; a house built on the shifting sands of nickel will fall; "holes in the brain" will advance life; and the fate of the world will hinge on the production of a toxic gas named oxygen.

Song One: From Nothing to Stars, starring "Math."

Start with one simple observation: every galaxy in the universe is receding. Run this process backwards and everything, space, matter, even time itself, converges, starting as a burst of vibrating light from a single point, or, musically, a single tone.[28] Like fireworks, the spreading light cooled and clumped.[29] Some bits of matter were magnetically charged, negative or positive. The Laws of Physics made positive bits (protons) big and heavy, and negative bits (electrons) small and light. The equations for magnetic attraction work for any size, even electrons and protons, so positives and negatives attract, pairing off into stable neutral atoms. The electron skitters around the proton like a hyperactive Pomeranian leashed to a post,[30] its average position calculated precisely from charge and mass.[31] The electron is so

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[27] To quote Abraham Joshua Heschel: "Unlike the space-blinded man to whom all hours are alike, qualitiless, empty shells, the Bible senses the diversified character of time." [(1975) *The Sabbath,* Farrar, Strous and Giroux, p.8.] To remember our creation is a Sabbath of sorts. In fact, "Aquinas claimed that one of the reasons why God gave us the third commandment is that 'the Holy Spirit saw that in the future some men would say the world had always existed.'" [Hauerwas, S., and W.H. (1999). *The Truth About God: The Ten Commandments in Christian Life*. Abingdon, p. 59.] The first scientific conclusion reached in this lecture is that Aquinas was right: the world has not always existed.

[28] "Had you been alive, you would have seen a blinding, featureless glow all around you." [Musser, G. (2009). "Light." *Scientific American*, 301(3), 96.]

[29] Energy (E) became matter (m) because E=m times c^2. The uniformity of the very early universe was directly observed by the Cosmic Background Explorer. When this was reported it was often noted that creation from a single point implies a creator: "I recall watching television journalist Garrick Utley reading the news of the discovery of the background radiation with wide-eyed astonishment, believing it to be the confirmation of creation. He was justified in his response. It was the best news that ever came over NBC." [Dallas Willard (2009). *Knowing Christ Today: Why We Can Trust Spiritual Knowledge*. HarperOne Publishers, p. 224.]

[30] To understand the smeared-out nature of the electron, imagine trying to take a picture of that Pomeranian with a camera where the shutter must stay open for a full second.

light that you must treat it as light: not as a particle, but as a wave, not sitting still like a brick, but vibrating through space like a plucked piano string. Music is ordered vibration and electrons are, too.

Proton plus electron makes the simplest atom, #1 hydrogen. To build a periodic table, use the same equations to add a second electron moving around a second proton, then a third, and so on. Energy twists the electron waves, just as a tightened plucked piano string will twist more, producing overtones that are mathematically predicable and universal. These twists elongate the electron wave, so that three long electron waves can fit around a nucleus, one high, one wide, and one deep. Higher energies introduce new five twists, then seven. Because electrons can pair up you double these numbers, then spread them out, fill in underneath, split them like this (don't forget helium), double all levels and all of the sudden you have the periodic table.[32] Vibrating strings produce harmonic tones by integer relationships; the elements have vibrating electrons that also count by integers. (The musical analogy runs so deep that in chemistry, a stable electron wave delocalized across atoms is said to *resonate.*) From these numerically ordered vibrations, and from a point smaller than a mustard seed,[33] a universe was born.[34]

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[31] As a senior at SPU you can learn how this works for hydrogen. Figuring out how more electrons move around bigger, heavier elements requires a few more tricks, but is still fundamentally a calculation of how a big positive charge attracts and constrains small negative charges.

[32] Illustration inspired by Harry Kroto. This is how periodic table was built: electrons counting one, three, five, seven. Any universe with our physical laws has this periodic table. We cannot make the periodic table work with different laws, with a bigger electron or smaller proton: the universe either never makes anything but hydrogen and helium, or they all get made in collapsed lumps and never spread out. Rees, M. (2000). *Just Six Numbers: The Deep Forces That Shape the Universe.* Basic Books.

[33] God "starts small" in that there is Anunciation before Incarnation: if the second Adam has to start as an embryo, perhaps the first Adam did as well?

[34] Immediately there is a dissonance between this story and human experience. When you trace the path of the receding galaxies back to their common point, you get an estimate of the age of the universe at about 13.7 billion years. Not only that, but the galaxies are unimaginably far away, so far that right now we can only hope to reach them in our imaginations. The initial response to this spatial and temporal vastness is a philosophical vertigo. John Updike relates this sense in his poem "Angel Bones," as he describes looking up at the bishop's palace next to the cathedral at Rheims, at the statues of angels and saints carved there. "Now chips and missing chunks give proof these hulks/on loan from Heaven fell prey to earthly harm,/for limestone, being soft to sculpt, breaks easily./Look here! – a sheared and fractured flank reveals/a tiny shell, distinct, intact,/from vanished, darkling, long pre-Christian seas./The pious masses, milling underneath/and looking up to holy largeness, lacked/the science to deduce from this small clue/what mighty absence it might mean." [Updike, J. *The American Scholar*, Summer 2005.] This "mighty absence" in the silence of vast space and deep time is countermanded by C.S. Lewis when he describes his protagonist Ransom's first experience traveling through space: "A nightmare, long engendered in the modern mind by the mythology that follows in the wake of science, was falling off him. He had read of 'Space': at the back of his thinking for years had lurked the dismal fancy of the black, cold vacuity, the utter deadness, which was supposed to separate the worlds. He had not known how much it had affected him till now --- now that the

Song Two: From Stars to Heavy Atoms, starring "Entropy."

Eventually gravity gathered hydrogen in a ball so massive that its weight crushed 1-proton hydrogen and 2-proton helium together.[35] (Helium, from *helios* meaning sun, was first found in the sun.) Because helium is more stable, extra energy bursts out as light and heat, igniting a star. Two heliums collide making #4 beryllium. One more helium makes #6 carbon, then #8 oxygen.[36] Stars build the periodic table like this. Atoms heavier than #36 krypton are too heavy to be abundant; life uses half of the first 36, spread out throughout the columns of the periodic table, about one representative per row.[37] The

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very name 'Space' seemed a blasphemous libel for this empyrean ocean of radiance in which they swam. He could not call it 'dead'; he felt life pouring into him from it every moment. How indeed should it be otherwise, since out of this ocean the worlds and all their life had come? He had thought it barren; he saw now that it was the womb of worlds, whose blazing and innumerable offspring looked down nightly even upon the Earth with so many eyes – and here, with how many more! No: Space was the wrong name. Older thinkers had been wiser when they named it simply the heavens – the heavens which declared the glory … " [Lewis, C.S. (1938). *Out of the Silent Planet*, p. 35.] Or we can apply the reaction of G.K. Chesterton: "I do not believe in dwelling on the distances that are supposed to dwarf the world; I think there is even something a trifle vulgar about this idea of trying to rebuke spirit by size." [Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press p.155.]

[35] (Using the higher math equation 1+1=2; neutrons make it a more complex equation: 2+2 =4.)

[36] Life requires a balance of carbon and oxygen. But there's a problem: beryllium is the bridge, and half of the beryllium breaks down in 10^{-17} seconds. If the system is overwhelmed with helium, then because oxygen is also stable, most of any carbon could be turned immediately into oxygen. This does not happen because carbon has a special "resonance level" that oxygen does not, which helps more carbon form, and equal amounts of carbon and oxygen are produced. Fred Hoyle discovered this and wrote, "A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology, … ." [McGrath, A. (2009) "Lecture 3: The mystery of the constants of nature." Gifford Lectures, http://www.abdn.ac.uk/gifford/lecture-texts/ , p. 13-14.] Martin Rees remarks "Livio et al. (*Nature* 340, 281, 1989) have computed just how sensitive the carbon production is to changes in the nuclear physics." [Martin Rees (2000). *Just Six Numbers: The Deep Forces That Shape the Universe*. Basic Books (New York), p. 163.]

[37] Some gaps appear, for unstable atoms like boron and beryllium. The iron peak occurs because iron has the most stable nucleus. [CoE p.40.] "Accounting for the properties of the different atoms—and realizing that the Creator didn't need to turn ninety-two different knobs – is a triumph of astrophysics. Some details are still uncertain, but the essence depends on just one number: the strength of the force that binds together the particles (protons and neutrons) that make up an atomic nucleus. … [A] change in ε would affect the length of the periodic table. A weaker nuclear force would shift the most tightly bound nucleus (which is now iron, number 26) lower down the periodic table and reduce below ninety-two the number of stable atoms. This would lead to an impoverished chemistry. Conversely, a larger ε would enhance the stability of heavy atoms. … little would be added by enhancing the number of abundant elements, or by having a few extra stable elements beyond our natural ninety-two. The actual mix of elements would depend on ε, but what is remarkable is that no carbon-based biosphere could exist if

abundance of helium makes even-numbered atoms abundant, so life tends to use those.[38] We can see these in starlight,[39] and when old stars explode, their precious heavy atoms spread out. Gravity then clumps these clouds of matter into new stars. Everything here formed in the heart of a star.[40] This kind of process, of spreading through the void of space and of occasional fruitfulness one-hundred-fold, resonates with the portrait of God as a sower, on a cosmic scale. Sowing is a process of spreading out; in chemistry such spreading out is measured as thermodynamic entropy.

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this number had been 0.006 or 0.008 rather than 0.007." [Martin Rees (2000). *Just Six Numbers: The Deep Forces That Shape the Universe*. Basic Books (New York), p. 47, 50-51.]

[38] See figure 1.1 from CoE p.3:

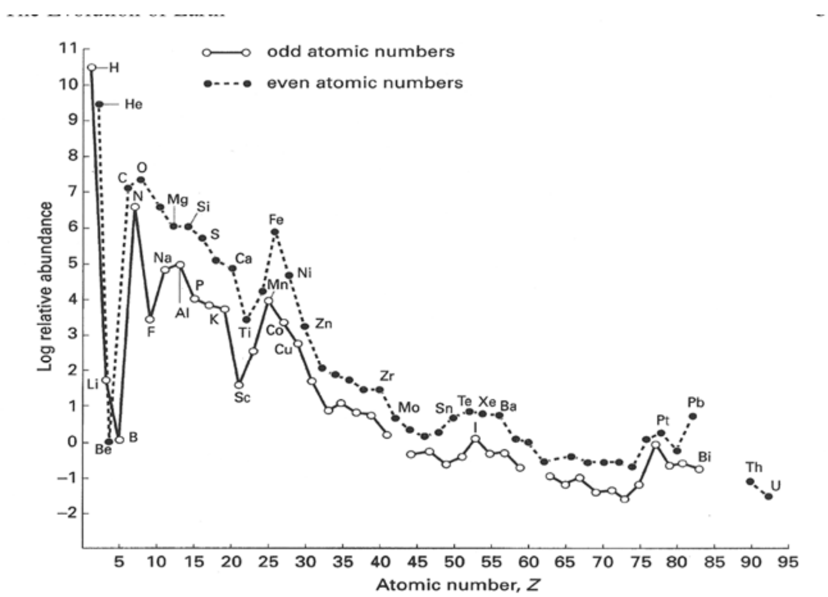

FIG. 1.1. Relative abundances of the 'unchangeable' elements in the universe (based on log (abundance of Si) = 6). Filled circles (•), even atomic numbers; open circles (○), odd atomic numbers. ('Unchangeable' refers here to atoms of elements. Thus we ignore, for the purposes of this book, any transmutation of elements.)

[39] See CoE Fig 8.2.

[40] Katharine Paterson drew from this concept when writing the ending to the children's classic *The Great Gilly Hopkins*: "On the back of the magazine was a dramatic photo of supernova remnant Cassiopeia A and under the picture this quotation: ' … Silicon, sulfur, argon, calcium, and iron were among the elements indentified from Chandra's X-ray image. "These are the materials we are made of," said the project scientist. 'The thrill that every writer recognizes went through my body. I knew I had an idea for a book in that quotation. Eventually, I recognized it as the missing strand I needed … What would it mean to a child that the world has discarded as waste to learn that she was made of the same stuff as the stars?" ["Are You There, God?," *Harvard Divinity Bulletin*, Spring 2005.]

Two opposing trends are at play: gravity clumps but entropy spreads energy and matter. This pushing and pulling causes the great cycles and music of life. Consider this Crookes radiometer.[41] It is just a bulb with a propeller in it: light and entropy turn it. Notice the black side is pushing; light heats it up like asphalt in July. The hot air atoms jostle about, pushing the propeller. The heat coming out is more spread out than the light coming in; in fact, energy spreading out *causes* this cycle. Increased heat means increased entropy, and yet an organized, flowing cycle results, ultimately dependent on the light. Life works the same way: it too is a cyclic chemical reaction driven by sunlight, with energy stored in chemical bonds and later released as heat, saving and then degrading high-entropy sunlight to low-entropy heat, emitting less effective energy.[42] Efficiency for life's cycle is measured as how much light can be captured, transformed into chemical bonds and then heat.[43] This cycle both builds bonds and increases entropy. Its energy flow drives the flowing chemical cycles of life.[44]

Now imagine that this propeller can change its shape or color; that it can *flow* in some way. If the new propeller captures more light, it turns faster, and more light is spread out as heat. The second law of thermodynamics says that a system with increased entropy is more probable. An adaptable propeller

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[41] Picture from http://www.thinkgeek.com/geektoys/science/9bec/

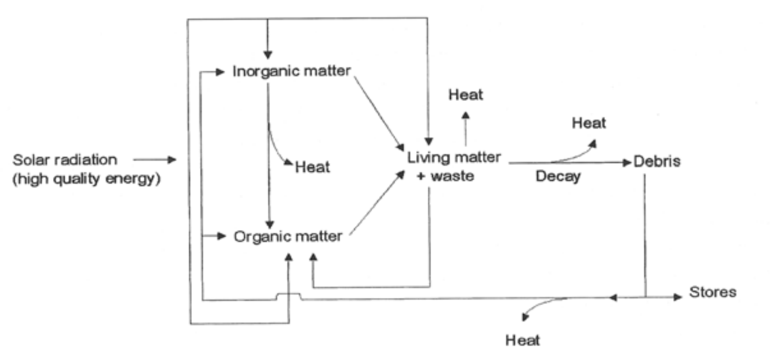
[42] 

FIG. 3.7. An outline of the ecological system of flow of material and energy (see Jorgensen *et al.* in Further Reading).

[CoE p.87 Fig. 3.7. "Effective" language on p.94.] Note that it is a cycle, not an equilibrium. Equilibria are chemically dead, and "An equilibrium system cannot flow, much though atoms or molecules exchange positions randomly and isotropically." CoE p. 81.

[43] CoE p.153

[44] I suggest that anyone who doubts that living things automatically spread matter and energy out babysit a small child for an afternoon and observe the resulting environment carefully.

will maximize entropy increase, and spin faster. An adaptable system will become more efficient at producing entropy and heat.[45] This works for chemical and biological cycles as well.[46] Entropy does not doom life to futility; entropy turns the cycles of life. If the seed never spread out, the Sower's work would be in vain.

Song Three: From Heavy Atoms to Earth, starring "Gravity."

Gravity pulled together iron, nickel, and other heavy-atom debris from solar plumes into planet Earth. The solar wind blew away most of the chemically boring hydrogen and helium. The rock had enough gravity to hold on to the heavy gases CO_2, nitrogen, and water.[47] As it cooled, some elements started to share electrons, forming compounds according to abundance and bond stability (that is, the best arrangement of electron-sharing). Like a game of musical chairs, some stable compounds formed first, leaving others unformed, stranded without chairs. The chemical stabilities of oxides vs. sulfides tell

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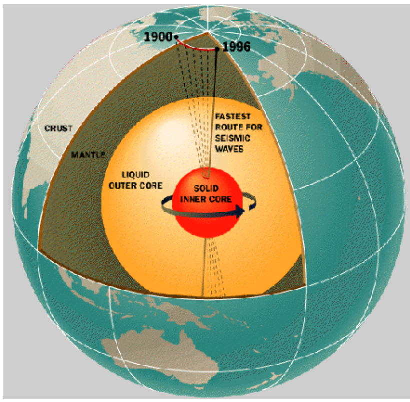
[45] This is a kinetic restatement of the Second Law of Thermodynamics. The most effective cycle must balance optimal entropy production with optimal (hopefully element-neutral) use of materials. See CoE p.427.

[46] [CoE Fig 3.14] [see Figure in Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, 323-343.]

[47] Farther away solar wind was weak and heavy atoms scarce, so the planets out there have diffuse clouds of hydrogen and helium. See CoE Table 16.7 for a list of the special characteristics of the Earth.

which metals won the atomic tussle for oxygen and sulfur.[48] Most important is that iron is less stable with oxygen than magnesium and aluminum, and so we had aluminum oxide rocks and water-friendly iron sulfide, not water-unfriendly iron oxide rust.[49] Later, these numbers will determine what dissolves in the ocean versus what remains unavailable, locked up in sediment.



The cool surface of the earth formed a solid crust "blanket" that kept the interior hot and liquid. Deep down, the pressures are just high enough to crush iron and nickel into a solid core suspended in liquid, like a cherry cordial, that can turn.[50] Planet size and composition must be chemically balanced with the phase diagram of iron-nickel to produce this kind of solid-liquid-solid planet. Because the core is magnetic and moving, it produces a magnetic

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TABLE 1.4
HEATS OF FORMATION OF OXIDES AND SULFIDES AT 25°C (KCALS)

	ΔH_O oxide/per O	ΔH_S Sulfide/per S	$\Delta H_O - \Delta H_S$ difference (O–S)
Mg	−143.8	−83.0	−60.8
Al	−130 (Al_2O_3)	−40.5	−89.5
Ca	−151.9	−115.5	−36.4
Mn	−92.0	−48.8	−43.3
Fe	−63.7	−22.7 (FeS_2−21.5)	−41.0
Co	−57.2	−20.2	−37.0
Ni	−57.8	−18.6	−39.2
Cu	−37.1	−11.6	−25.5
Zn	−83.2	−48.5	−34.7
Cd	−60.9	−34.5	−26.4
C	−47.0(CO_2) −26.4(CO)	+13.8 (CS_2)	−60.8
Si	−102.2(SiO_2)	−17.4 (SiS_2)	−84.8
P	−72.0(P_4O_{10})	—	—
N	+21.6(NO)	+31.8 (NS)	−10.2
Na	−99.4(Na_2O)	−89.2 (Na_2S)	−10.2
K	−86.4(K_2O)	−100.0 (K_2S)	+13.6

Note: Heat of formation is the heat of reaction at 25°C, e.g.

$$M\ (solid) + \tfrac{1}{2}\,O_2\ (gas) \rightarrow MO\ (solid)$$

and the corresponding reaction for sulfur. Elements with strong element M lattices appear to have small ΔH.
Note the sequences Mg > Mn > Fe > Co (Ni) > Cu < Zn of MO and MS which also shows the preference for oxygen over sulfur (O–S).

[from CoE p.11]

49 Also, carbon is much more stable with oxygen than with sulfur, so we have a lot of carbonate and carbon dioxide, but not much carbon sulfide.

50 Figure from http://wps.prenhall.com/wps/media/objects/1351/1384326/image/ld_core_spin.gif

field that repels solar wind: an invisible umbrella.[51] Mars has no such umbrella, so its atmosphere was quickly stripped away, despite its distance.[52] The layers of chemical phases beneath us keep our atmosphere in place.[53] This resonates with 1 Kings, when Elijah's servant opened his eyes and saw angels on the hills; we turn on instruments and see the invisible protection of the Van Allen belts.[54] Therefore the sun shall not smite us by day.[55]

Song Four: From Rock to Sea and Sky, starring "Water."

Once the earth's interior divided into core, mantle, and crust, its surface divided into solid, liquid, and gas, which we know better as soil, sea, and sky. For most of the Earth's existence, all three phases of water have been present. Third out from the sun is a special place: surface temperature is 15 degrees Celsius plus or minus 25, and atmospheric pressure puts us by the "triple point" of water,[56] where some water is gas, some solid, and most important, much is liquid. As Earth cooled off and outgassed, it stabilized at near-constant temperature and pressure where it had oceans of flowing liquid water for

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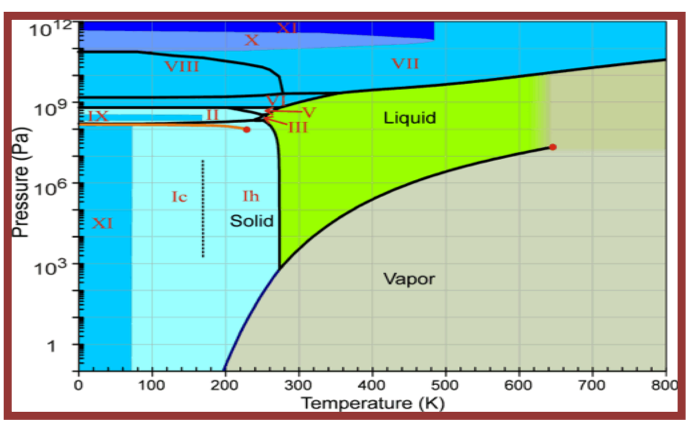
[51] This is the same magnetic field that attracts a magnetized needle to point north.

[52] Spradley, Joseph L. (2009). "Importance of the Moon for Life on Earth." ASA Meeting Lecture available online at www.asa3.org.

[53] Not only that, but the Ni and Fe of the core had to be kept from the water; at the temperatures of the early earth, the metals would have reacted with water, turning it into hydrogen! But light elements floated to the top and cooled early (Mg and Si), forming a solid shell that kept water safe from the Fe/Ni core. In the words of Williams, "deeper levels of minerals cannot equilibrate." See CoE p.15-16.

[54] As William Blake saw "angels in the sunshine."

[55] By the way, the size and location of the moon stabilizes the earth's rotation. Even the tiny wobble that remains is enough to cause ice ages, so anything worse may be incompatible with life. See Spradley lecture above.

[56]


[Our current conditions are at $P=10^5$ Pa and T = 300K; the triple point is the intersection of solid lines below that.]

seven-ninths of its lifespan, a vast, flowing environment for biochemical experimentation.[57] When the sun was young and weak, we had a CO_2 greenhouse-gas atmosphere and still a lot of hydrogen, with all the oxygen in the rocks, nothing left for the sky.[58] Excess hydrogen made the ocean as acidic as lemon juice.[59] This had to change so the dust of the earth could form chemicals that would persist and live. As

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57

Table 15.19 Changes of variables and derived variables on Earth

Time (years)	Components and compartments	Temperature (K)
5×10^9	90 elements equilibrated	1000–5000
4.5×10^9	Core and mantle equilibration; crust continuously changes	300–400
3.5×10^9–$+1.0 \times 10^9$	As above plus release of O_2; set of 20–30 elements + large number of compartments gives life	273–373
1.0×10^9–4×10^4	As above; little change in chemistry: large changes in compartments in life	273–373
4×10^4–today	As above plus large change in man's industrial chemistry; 90 elements not equilibrated; large increase in external compartments	100–10 000

[CoE Table 15.19]

Thales of Miletus first to connect water with life through flow. [*"In the Beginning" Scientific American;* Sep2009, Vol. 301 Issue 3, p35-35.]

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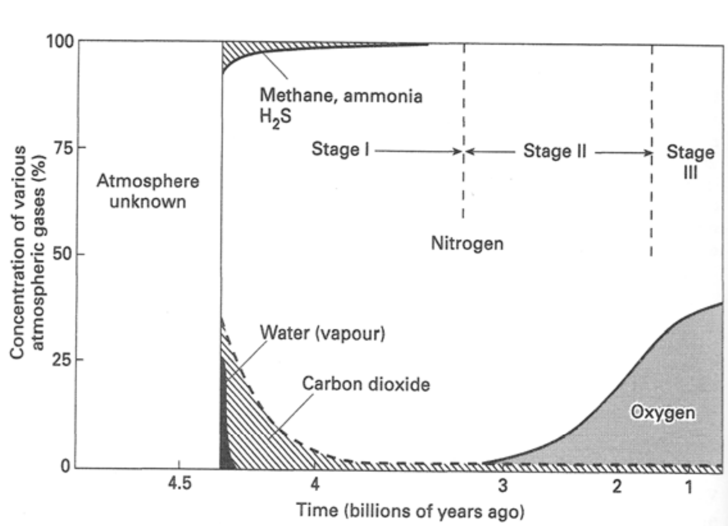

Fig. 9.2 Atmospheric composition, shown by the relative concentration of various gases, has been greatly influenced by life on Earth. Note that the total pressure has fallen greatly, and light gases have been lost in part, but nitrogen always dominates.

Williams, R.J.P. and J.J.R. Frausto da Silva (1999). *Bringing Chemistry to Life: From Matter to Man*. Oxford University Press, p.254.

[59] pH ~ 2.

the sun strengthened, that CO_2 disappeared and the temperature remained even, and the oceans became pH neutral. This happened because of water: it cooled into rainclouds, and rainwater dissolved dirt and made it part of the sea. Dirt contains oxides, sulfates, and carbonates,[60] bases that absorb hydrogen and neutralize acid. Also, dirt has calcium, which binds CO_2 as solid calcium carbonate mountains. So dissolved dirt both titrated the lemon-juice oceans to neutrality *and* drew down the CO_2 greenhouse blanket into mountains of calcium carbonate limestone, maintaining constant temperature and pH neutrality.[61] This resonates with the scripture that our Father knows how to give good gifts, here given through the availability of calcium and the stability and buffering capacity of its carbonate, in the fullness of time.

Song Five: From Sea and Sky to Sulfur, starring "Bubbles."

Once the stage was set, life came about very quickly, according to isotopic evidence in rocks. To a chemist, the miracle of creation of life appears at the conception of the universe in the periodic table, in how its simplicity could lead to complexity. The rules of chemical reactivity predict the early earth had eight flowing reactive chemicals: hydrogen; carbon-plus-four-hydrogens, one-oxygen or two-oxygens; nitrogen-plus-three-hydrogens or carbon; sulfur-plus-hydrogens; and phosphorous-plus-oxygens.[62] Amazingly, we can see echoes of these eight original "LEGO blocks" in all biopolymers: sugars, DNA, proteins, *and* fats. For example, CO plus H_2 equals H_2CO, a.k.a. "formaldehyde," carbon-plus-hydro,

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[60] Hard water contains high amounts of these soluble earthy elements.

[61] This never happened on Mars or Venus, which still have atmospheres of >90% CO_2. [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 71.] Later, life also contributed to the fixing of CO_2 and the production of O_2.

[62] CoE p.139

“carbohydrate.” Formaldehydes add up to make sugars.[63] Likewise, the twenty amino acids[64] and five nucleic bases can be traced back to these eight molecules. The eight building blocks of life combine in abiotic processes that can be captured by a biotic system,[65] creating kinetically stable biopolymers which store energy in their bonds to be degraded later, releasing heat and increasing entropy.[66]

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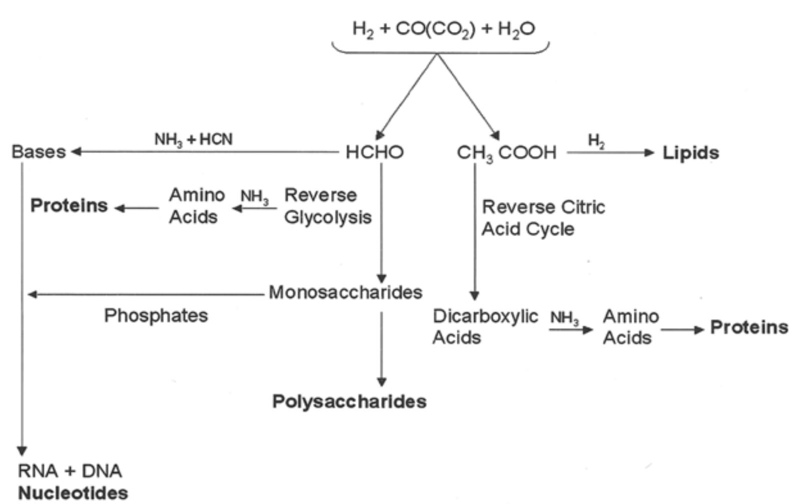
63 

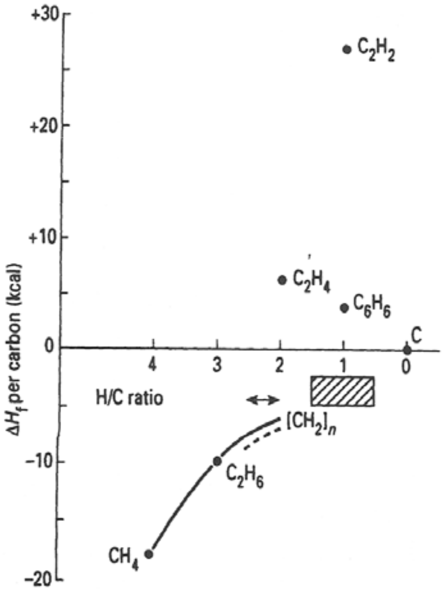
FIG. 4.4. Non-metal material input to cells.

CoE p.139.

64 The 20 amino acids combine into protein polymers, which form rod structures (alpha helices) and platforms (beta sheets). “Consider the parallel with the components of a car engine. There are moving parts, rods and valves, and basic platforms and cylinders, typical of all mechanical devices, connected to energy input and work. Can we devise polymers other than proteins, which will act on such a molecular scale in water as highly selective catalysts, as structures and/or as mechanical devices? … Given the variety of functions they can perform, are they unique polymers?” CoE p.164.

65 CoE p.201.

66 CoE p.132.



The first thing life needed was a fence, which could have been soap bubbles.[67] Soap molecules are simply carbon chains with oxygen on one end. This graph shows that carbon chains are more stable than carbon chunks, so chains will happen automatically as hydrogen pressure drops.[68] Many metals can transfer oxygen to carbon chains, making soap. In water, a double-sided soap bubble forms, separating "inside" from "outside." Bubbles are dynamic fences that flow. They join and separate, re-bubbling and reproducing. You can still watch bacteria that reproduce by budding, which is blowing bubbles of baby bacteria,[69] and tiny bubbles that look like fossil microbes are in ancient rocks.[70] Such a bubble defines a chemical space that can trap energy efficiently; [71] it limits diffusion and controls flow;[72] in other words, it becomes alive.

All cell interiors are the same. First, the inside always has extra electrons.[73] Chemically, electrons stick with hydrogen, called a "reduced" state, because electrons are negative. The crucial flipside to this is that hydrogen and electrons are chemical opposites of oxygen. If all cells are reduced with more

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[67] This is the "Lipid World" hypothesis, given recent experimental support by the work of Stoszak (see below). [Segre, D.; Ben-Eli, D.; Deamer, D.W.; and D. Lancet. (2001). "The Lipid World." *Origins of Life and Evolution of the Biosphere* 31: 119–45.]

[68] **Fig. 9.5** The relative standard state heat of formation, ΔH_f, of C/H compounds per carbon atom. Solid line, linear chains; broken line, branched chains; double-sided arrow, cyclic XH_2 units; cross-hatched region, multiple rings (steroids). See figure From Williams, R.J.P. and J.J.R. Frausto da Silva (1997). *The Natural Selection of the Chemical Elements.* Clarendon Press (Oxford), p.330

[69] Leaver, M.; Domınguez-Cuevas, P.; Coxhead, J.M.; Daniel, R.A. and J. Errington (2009). "Life without a wall or division machine in *Bacillus subtilis*." *Nature* 457, 849-853.

[70] Picture in *What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. p.131.

[71] CoE p. 103.

[72] CoE p.136.

[73] Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, 329.

electrons on the inside, then the outside must have fewer electrons, and is therefore oxidized.[74] This disproportionation of electrons-inside/oxygen-outside can start wherever captured energy separates two charges.[75] Rejecting oxygen helped biopolymer chains persist inside, because oxygen is indiscriminately reactive, shattering chains.[76] Also, the available food forced early life had to be "reductive": it has oxidized molecules CO and HCN on the menu,[77] so it had to *peel off* oxygen and add hydrogen to make biopolymers. This reaction happens at a chemical potential of -0.6V, decidedly "reduced" below the environmental potential of -0.2V.[78] If the environmental potential were not different in this direction, then oxygen would not be available to play its unique role later. The drive to oxidation is the drive to life, and this little negative number made all the difference.

Life's bubbles are more stable if they hold in stabilizing material and eject destabilizing material.[79] Such disproportionations must be balanced. Just as electrons gather inside and oxygen outside, positive potassium gathers inside, positive sodium outside; negative phosphate inside which carries along bound magnesium,[80] as negative sulfate is rejected outside. Disproportionation is the lynchpin and dramatic

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[74] A single number that sums up whether electrons or oxygen are winning the balance of power is the reduction potential of the system. The Earth probably started at a balanced but slightly reducing potential around -0.2V. By 2 billion years ago, the appearance of Banded Iron Formations indicates the environmental potential had risen to around +0.0V and today it is higher. [CoE p.22] These constitute "90% of Earth's current mineable iron deposits in present-day southern Africa, Brazil, Central America, western Ontario, northern Michigan, and Minnesota forms between 2,400 and 1,800 mya." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. p. 59.] "They are the source of the iron used in Detroit-built cars." [ibid p. 82]

[75] An example is petroleum: it was once alive, it is highly reduced, so much that oxidizing it (that is, burning it with oxygen) releases energy.

[76] Today, reduced elements in the air signal danger: reduced nitrogen is ammonia, reduced carbon is methane, reduced sulfur is sulfur dioxide, the smell of red tide. These tell us that the environment is reducing, not oxidizing, and that it is not fit for our type of life. Oxygen is chemically dangerous enough that it is a weapon. If you zap the tough protein plaques found in Alzheimer's disease with a laser they will fall apart, not from radiation, but because the laser creates destructive oxygen radicals. So oxygen is worse than a laser gun for biological polymers. [Ozawa, D. *et al.* (2008). "Destruction of Amyloid Fibrils of a β2-Microglobulin Fragment by Laser Beam Irradiation." *J. Biol. Chem.* 284, 1009-17.]

[77] CoE p.170.

[78] Figure CoE p.180 for formaldehyde formation from CO using H_2S, in which sulfur is the oxidized waste. Interestingly, the cytosol is still at around -0.2V potential today, and this means that the +0.8V potential of the oxygen-water reaction is "a very large energy store"; CoE p.187. If -0.6V were not below -0.2V, then there would have been no oxidizing "push" to life; and life may never have become more complex than prokaryotic anaerobes. See CoE p.310.

[79] CoE p.103

[80] This is because magnesium binds oxygen better than sulfur. Mg fits perfectly in the cracks between multiple phosphates in ATP.

center of our story, and there is a chemical logic to it.[81] Sodium must be ejected to balance out osmotic pressure.[82] Calcium must be ejected because it is *too* good at binding: its high charge density sticks to negatively-charged phosphate, cross-linking phosphate in DNA into calcium-phosphate masses that resemble kidney stones or bone.[83] The rejected molecules can eventually be used, but must remain *outside* the cell.[84]

The concentration of free metals inside is chemically predictable: it is the inverse of the Irving-Williams series of binding strength in which electron-dense metals stick better to organics;[85] the result is that

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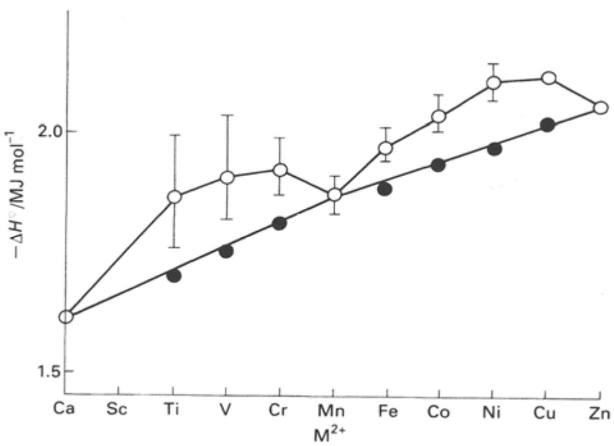
[81] Most metals that end up inside are stable when surrounded by water, being higher in hydration enthalpy on this graph [From Williams, R.J.P. and J.J.R. Frausto da Silva (1997). *The Natural Selection of the Chemical Elements.* Clarendon Press (Oxford), p.164.]

Fig. 5.6 The hydration enthalpy of M^{2+} ions of the first row of the *d* block $\Delta H°$. The filled circles show the trend when the ligand-field stabilisation energy has been subtracted from the observed values. Note the general trend to greater hydration enthalpy (more exothermic hydration) on crossing the period from left to right. The ligand-field energy here includes covalent radial terms due to 3*d* orbitals. Values are relative to $\Delta H°(H^+) = -1.09$ MJ mole^{-1}.



[82] CoE p.174

[83] Williams, R.J.P. and J.J.R. Frausto da Silva (2003) “Evolution was Chemically Constrained.” *J. Theo. Biol.* 220, 335. What was good for removing CO_2 from the atmosphere is bad for the single cell. Likewise, Rick Ridgway’s biology lab has found that high concentrations of zinc will turn his snail cells into a cross-linked mass of mush. On phosphate binding, see CoE p.173. This rejected calcium could cross-link and stabilize the exterior walls of bacteria as a bonus. It is also used to help digest material outside the cell wall. CoE p.210.

[84] CoE p.235. Interestingly, H_2S itself is in a special category in that it crosses the membrane without difficulty or transporter, unlike H_2O. [Mathai, J.C.; Missner, A.; Kugler, P.; Saparov, S.M.; Zeidel, M.L.; Lee, J.K.; and P. Pohl. (2009). “No facilitator required for membrane transport of hydrogen sulfide.” Proc. Natl. Acad. Sci. USA, 106 (39), 16633–16638.] Also in this special category: nucleotides, which cross protocell membranes despite their charge and *polymerize* on the inside. [Mansy, S.S.; Schrum, J.P.; Krishnamurthy, M.; Tobé, S.; Treco, D.A. and J.W. Szostak. (2008) “Template-directed synthesis of a genetic polymer in a model protocell.” *Nature* 454, 122-125.]

[85] In the words of Waldron et al., “some metals tend to bind organic molecules more avidly than others.” Waldron K.J., J.C. Rutherford, D. Ford, and N.J. Robinson (2009). “Metalloproteins and Metal Sensing.” *Nature* 460, p.823-830. Another way to look at this is as an issue of solubility in the presence of O, N, and S.

tight-binding metals with lots of electrons like copper are rejected while weak-binding metals with fewer electrons like magnesium are included in the cell.[86] Free ion concentration is constrained in every

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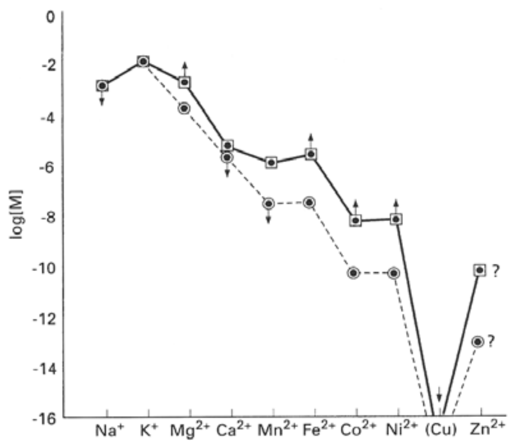

FIG. 5.3. The proposed free metallome profiles of a primitive organism after the synthesis of ring chelates: ◉, free metallome; ▣, combined or total metallome. Arrows (up) indicate the elevation due to the chelates and arrows (down) indicate pumping out.

CoE p. 207.

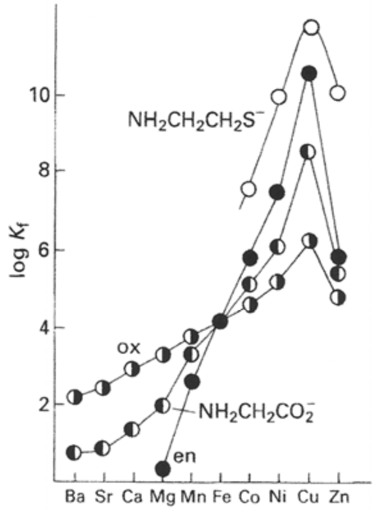

FIG. 2.8. The variation of stability constants, K, for the complexes of M^{2+} ions of the Irving–Williams series, ox, oxalate; en, ethylenediamine (note that the constants plotted are absolute, not "effective" constants at pH = 7).

CoE p. 67.

Note how this plot of stability is the opposite of the former plot of cytoplasmic concentration. Both are related to the Irving-Williams series: the former inversely, the latter direction.

[86] This is exactly what chemists do when analyzing complex metal ion solutions: we react the tight-binding copper first to make it precipitate out of solution as sulfide, then nickel, then cobalt and iron. (CoE p.66.] Evidence for the importance of the Irving-Williams series to metal levels within a wide range of bacterial cells, and a discussion of how cells manage the proper binding of these ions to proteins, is nicely summarized in Waldron, K.J. and N.J. Robinson (2009) "How do bacterial cells ensure that metalloproteins get the correct metal?" *Nature Reviews*

cytosol, in every cell, so that binding can happen a little but not too much.[87] This binding series is biologically constant, constrained by inherent binding reactivities.

Different metals are useful for different things. If you add iron, copper, zinc, and cobalt to different acids you get very different results; and if you add nickel, nothing happens. Metals are so important to some enzyme functions that changing the metal can change what the enzyme does: trading manganese for magnesium changes a kinase into a cyclase.[88] Life ignores the first three columns of the transition metals because they don't bind anything.[89] Moving to the right, sulfur binding increases more than oxygen binding, simply because sulfur has more electrons than oxygen.[90] This subtle difference explains why the old sulfur-dominated ocean had to use metals on the left, while our oxygen-dominated ocean uses those on the right.[91] The left side transfers oxygen and nitrogen; the right side transfers carbon and hydrogen; the far right sticks to everything.[92] Iron's position in the middle makes it the versatile switch-hitter, binding many different elements moderately, so valuable to life that it is hoarded and fought over.[93] These elemental personalities are fixed by the atomic sizes and positions in the periodic table.

Microbiology, Vol. 6, p. 25-35. Especially note Figure 3, which is calibrated to the Irving-Williams series! Two research directions are proposed: a description of the affinity of competing metals for the metal-binding proteins in a bacterial cell; and an investigation into the antibiotic use of the Irving-Williams series as a bacterial Achilles' Heel. (The "Williams" of the Irving-Williams series is the same "Williams" who co-wrote *The Chemistry of Evolution*.)

[87] "Thus, a cell compartment has imposed upon it equilibrium conditions of free element bindings – the free metallome is fixed by complex ion binding, solubilities and redox potentials outside and inside cells and by organic synthesis of ligands and pumping considerations inside cells." [CoE p.172.]

[88] Sanchez-Moreno, I.; Iturrate, L.; Martin-Hoyos, R.M.; Jimeno, M.L.; Mena, M.;Bastida, A. and E. Garcia-Junceda. (2009). "From Kinase to Cyclase: An Unusual Example of Catalytic Promiscuity Modulated by Metal Switching." *ChemBioChem* 10, 225-9.

[89] CoE p.225

[90] So magnesium is stuck into the grooves between the phosphates in ATP, while in a sulfur-rich environment all the copper and zinc are locked up in rocks as insoluble sulfides. CoE p.46 Fig. 2.5

[91] Because magnesium and zinc cannot move electrons around, they are used to move protons around; they are "safer" than others. CoE p.65; they are therefore used for communication [CoE p.302].

[92] CoE p.72-73.

[93] You sense iron's innate catalytic activity when your hand smells different after handling coins: the iron has reacted with your skin to make smelly aldehydes. [Glindemann D.; Dietrich, A.; Staerk, H.J.; and P. Kuschk. (2006). "The Two Odors of Iron when Touched or Pickled: (Skin) Carbonyl Compounds and Organophosphines." *Angew. Chem. Int. Ed*., 45 . 7006 – 7009.] Across all of life, electrons and hydrogen are added with iron, nickel and cobalt; electrons are taken away and oxygen added with iron, copper, and manganese. Whole atoms are transferred with molybdenum, tungsten, vanadium and selenium. (Specifically O/S/N transfer at lower potential; CoE p.171.) Mo can play some unique chemical tricks because it can assist two-electron reactions (Table 7.5 CoE p.296). Vanadium

Often the lightest available metal in that column is used because stars have not had time to make the others. For example, cobalt catalyzes about as well as iron, and binds tighter, but life does not use it much; probably because for every available cobalt there were 100 iron ions – so iron gets the star.[94]

Many early enzymes are built around an iron-sulfur chunk.[95] Sometimes a metal chunk will catalyze the reaction even when removed from the enzyme.[96] Is this a clue to the start of life?[97] Iron-sulfur clusters would be available, because after hydrogen left, the chemically dominant element in the ocean was sulfur, observed in ancient rocks and metal requirements of ancient microbes.[98] (Thus ocean history had three ages: first hydrogen, then sulfur, then oxygen.) The age of sulfur had high levels of iron, nickel and

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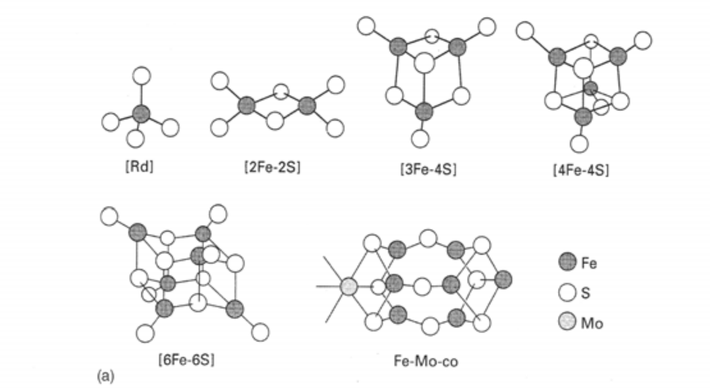
is the "missing element" in this story, simply because not enough research has been done into its biochemistry to see how it matches up with its physical properties. (See refs in CoE p.341)

[94] CoE p. 134; Higher plants have replaced Co with Zn, probably because of the differences in reactivity with oxygen vs. sulfur. CoE p.340.

[95]



[CoE p. 208] Specifically, the Fe-S clusters are "reminiscent of … greigite, pyrrhotite, violarite, and pyrite." (Fontecilla-Camps et al. (2009) "Structure-function relationships of anaerobic gas-processing metalloenzymes." *Nature*, 460, 814-822.)

[96] Specifically, for Fe-Mo-co in nitrogenase, which catalyzes the same interaction but inactivates quickly, suggesting a protective role for the protein. [Shah, V.K. and W.J. Brill. (1977). "Isolation of an iron-molybdenum cofactor from nitrogenase." *Proc. Natl. Acad. Sci. USA* Vol. 74, No. 8, pp. 3249-3253.]

[97] Iron sulfide also forms cell-like bubbles in its rich deposits around hydrothermal vents. [Martin, W.; and M.J. Russell. (2002). "On the origins of cells: a hypothesis for the evolutionary transitions from abiotic geochemistry to chemoautotrophic prokaryotes, and from prokaryotes to nucleated cells." *Phil. Trans. Royal Soc. London B*, DOI 10.1098/rstb.2002.1183.] Iron also flips from a high-spin to low-spin state, allowing cooperative allosteric changes like that in hemoglobin. [CoE p.217.] Is this one reason why Fe is used for blood instead of Cu? Chains of iron ions and iron-sulfur centers still form the wires through which electrons move in our mitochondria. [CoE p.70.] Electrons can only transfer up to 20Å without help from an iron atom. [CoE p.207.]

[98] Mak A. Saito, Daniel M. Sigman, Francois M.M. Morel. (2003) "The bioinorganic chemistry of the ancient ocean: the co-evolution of cyanobacterial metal requirements and biogeochemical cycles at the Archean/Proterozoic boundary?" *Inorganica Chimica Acta*, 356, 308-18.

cobalt, but low levels of copper and zinc, which bind sulfide as a solid that sinks to the ocean floor. Iron sulfide, a.k.a. pyrite or fool's gold,[99] carried energy from the earth's interior in its easily removable electrons.[100] Iron sulfide plus hydrogen sulfide gives stable iron disulfide, hydrogen gas, and most importantly, excess energy, which means this reaction can be a dynamo that pushes hydrogen onto something else, a "reducing" reaction. If the sulfides react outside a soap bubble, the electrons can be shunted inside through a chain of irons.[101] CO and CN^- are electron-poor and accept electrons from iron-sulfur clusters,[102] stitching together carbon chains. The inside of the bubble gets electrons for carbon chains and hydrogen, from just a chunk of pyrite and a bubble in a sulfur-rich ocean. Energy is trapped inside as the bonds that hold life together, leading the optimal system to be a cycle that turns with minimal waste or excess. Once a waste chemical builds up, its own excess will "push" forward reactions

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[99] Especially near "black smokers" such as the iron-sulfide-containing mineral on display at the Pacific Science Center.

[100] CoE p.54. According to Wachtershauser, [CoE p. 56] part of this may be because iron switches from a high-spin to a low-spin state when changing from its sulfide to its disulfide; it is the only abundant element that does. Today, denitrifying bacteria use pyrite as a "major" source of electrons in their reduction of nitrate to nitrogen gas. [Yan-Chun Zhang, Caroline P. Slomp, Hans Peter Broers, Hilde F. Passier and Philippe Van Cappellen. (2009) "Denitrification coupled to pyrite oxidation and changes in groundwater quality in a shallow sandy aquifer." *Geochimica et Cosmochimica Acta,* 73, 6716–26.]

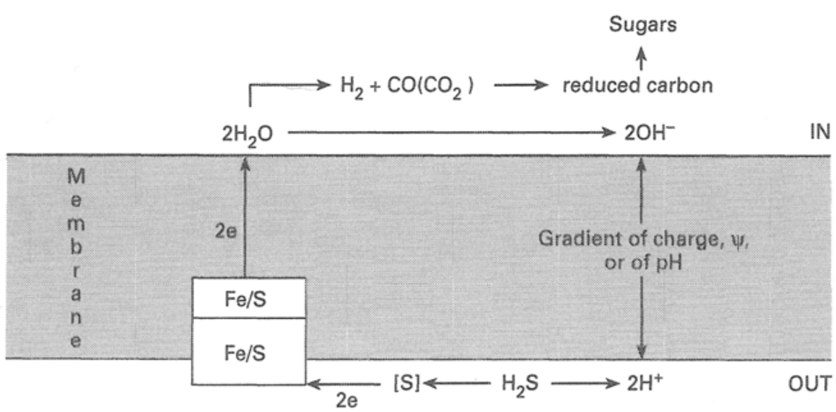

Fig. 11.6 A simplified description of electron flow and its connection to carbon oxide reductions using a membrane. It is the presence of a transition metal (Fe) that is essential. In fact, the electron transfer usually meets the proton transfer pathway in the membrane (see refs. 167–173). NO rather than H_2O could have been the oxidising agent being reduced to NH_3.

[101] [Williams, R.J.P. and J.J.R. Frausto da Silva (1999). *Bringing Chemistry to Life: From Matter to Man*. Oxford University Press, p.343.] Electrons may even land on water to produce hydrogen gas. The separation of hydrogen from oxygen is therefore a charge separation, and the same kind of separation will lead to both photosynthesis and brains later.

[102] CoE p. 171.

that use it[103] – through the freshman chemistry rule, Le Chatelier's principle – pushing it into a new cycle that can seek out and trap more energy in its bonds. All these cycles within cycles result from the periodic table, soap bubbles, and an ironic quantity of fool's gold.

Finally there are nucleotides, which can come from three simple chemicals: phosphate, formaldehyde and cyanide.[104] Just last year one lab found that two nucleotides self-assemble and self-catalyze from a complex mixture, not the individual components; this chemical song works with a full choir, but not a

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[103] For example, N_2 excess in the atmosphere can lead to N_2-fixing chemistry to complete a nitrogen cycle. Eventually plastic-degrading bacteria should evolve as well. See *What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 86.

[104] To make DNA you need nucleobases, ribose sugar, and phosphate to make a flexible, complex information-carrying chain that dissolves in water. "Heavy non-metals such as sulfur and phosphorus are also advantageous as carriers and catalyst centres of small organic groups for synthetic purposes due to their intermediate reactivity between light non-metals and metal ions." [CoE p.75. Also see CoE p. 132.] Nucleobases will form spontaneously from cyanide, acetylene, and water, but why did life pick only these five bases? Sugars are easy to make but unstable, and phosphate is abundant in rocks but relatively insoluble. [Ricardo, A.; Szostak, Jack W. (2009). "Origin of Life on Earth." *Scientific American*, 301 (3), p54-61.] Chemists could make ribose and base independently but they would not join. Just last year John Sutherland's lab mixed everything together in one big pot and found that phosphate assembles formaldehyde and cyanide derivatives into novel half-RNA molecule, which then reacts with phosphate to the natural cytidine we know and love. Cyanamide, cyanoacetylene, glycolaldehyde, glyceraldehyde and inorganic phosphate are the five ingredients. The key intermediate is 2-aminooxazole, which reacts to form arabinose anhydronucleoside: neither sugar nor base, but a half-sugar half-base chimera. This reacts with phosphate to form cCMP. The arabinose is actually volatile and will recondense and crystallize in cycles, flowing through the air and appearing on the ground like manna. As simple molecules catalyze more complex molecules, a spiral evolves that spontaneously spins out a mixture of nucleotides. Phosphate does five different things in this scheme: it acts as a pH buffer, then a catalyst, then it destroys an unneeded by-product, it protects a needed intermediate, and finally reacts with the nucleoside, opening it up to form the nucleotide. The final step is where UV light catalyzes the conversion of about half of the cCMP to cUMP. [Powner, M.W.; Gerland, B.; and J.D. Sutherland (2009). "Synthesis of activated pyrimidine ribonucleotides in prebiotically plausible conditions." *Nature* 459 p. 239-242.] This paper is particularly important as it came out nearly simultaneously to the release of *Signature in the Cell* by ID proponent Stephen C. Meyer, a book arguing, among other things, that RNA molecules are too complex to form from the constituents of an early earth. Since half of RNA can form from simple substituents, Meyer's general strategy of calculating astronomical probabilities for these events of early life -- without accounting for the possibility of metal catalysis, entropy promotion of order, or complex mixtures working in concert to new outcomes – is called into question in general. Modified nucleotides can even enter a protocell, hopping the bubble fence, and then spontaneously pair up on a template as if to replicate. [Ricardo, A.; Szostak, Jack W. (2009). "Origin of Life on Earth." *Scientific American*, 301 (3), p54-61.] As for the purines, adenine biosynthesis may be promoted by a "remarkable," low energetic barrier in its formation process: "The absence of any sizeable activation barrier for the cyclization of 7 to the (*Z*)-imino form of 9H-adenine (*Z*)-2 is quite remarkable, and it is this feature that allows for the formation of the purine skeleton from 7 without any further activation." [See Glaser, R.; Hodgen, B.; Farrelly, D.; and E. McKee (2007). "Adenine Synthesis in Interstellar Space: Mechanisms of Prebiotic Pyrimidine-Ring Formation of Monocyclic HCN-Pentamers." *Astrobiology,* 7(3), 455-70.]

duet. Now the great mystery is not how biomolecules came about, but how they were connected and encoded.[105] Which came first, the code or the metabolism it encoded?[106] Some are tempted to insert God into that gap. But my conclusion is that the sequence is otherwise a continuous story, from Big Bang to nucleotides and bubbles on one side and from unicellular life to us on the other, so that gap is small; and only a small god would fit.[107] We simply do not know whether the creation of DNA coding is inevitable or a statistical bottleneck that restricts the formation of life to one case in the universe. Whatever happened, happened remarkably quickly, in a geological flash, from my perspective an act of creation, encoded in the periodic table.[108]

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[105] Solving the problem of ribonucleotide biogenesis means the "main problem" of the RNA world is being addressed: "The main problem about RNA as a 'starter' genetic material is in the supply of monomers, as is being increasingly recognized, … . Something must have performed the fine-tuning necessary to allow such sophisticated molecules as nucleotides to be cleanly and consistently made in the first place." [Graham Cairns-Smith, (2003). "Fine-tuning in living systems: early evolution and the unity of biochemistry." *International Journal of Astrobiology* 2 (2) : 87–90.]

[106] For a review of some aspects of this particular debate, focusing on one of the metabolism-first proponents, see Whitfield, J. (2009). "Nascence Man." *Nature* 459, 316-9.

[107]There are hints in the arrangement of DNA codons that they are organized by biosynthetic pathway, that is, according to amino acids made from sugars as opposed to the citric acid cycle. [See CoE p.148 Table 4.8.] Another major gap may be the development of oxidative photosynthesis, but as discussed below, that has a possible inorganic chemical basis in the properties of manganese.

[108] Nutman A.P.; Mojzsis, S.J.; and C.R.L. Friend. (1997). "Recognition of ≥3850 Ma water-lain sediments in West Greenland and their significance for the early Archaean Earth." *Geochimica et Cosmochimica Acta,* 61, p. 2475-84.

Life accumulates carbon-hydrogen bonds, inevitably oxidizing the environment.[109] Nickel can make C-H bonds because it sticks to hydrogen, and it was available in water.[110] A quick glance across genomes finds old enzymes that use nickel, relics of an entire carbon-exchanging economy of microorganisms that both made and ate methane.[111] Methane cycles are perfect for a young earth because two gases, hydrogen and carbon dioxide, are food, meaning the flowing atmosphere provided food and carried away waste. But methane doesn't have much chemical power,[112] so to get any energy out of it at all, organisms had to specialize and cooperate to form communities of producers and consumers.[113] (Such

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[109] CoE p. viii. This is described in full in the Wood-Ljungdahl pathway of acetogenesis [Fontecilla-Camps *et al*. (2009) "Structure-function relationships of anaerobic gas-processing metalloenzymes." *Nature*, 460, 814-822.] For the carbon-accumulation reactions see CoE p.29.

[110] CoE p. 135. Nickel has the additional advantage that is does not require a porphyrin to enter the electron-rich low-spin state; once iron porphyrins developed, this advantage became unnecessary. [CoE p.171.]

[111] Using elevated levels of Ni and W as a genomic signature of methanogenesis is proposed by Zerkle, A. L.; House, C. H. and S. L. Brantley (2005). "Biogeochemical signatures through time as inferred from whole microbial genomes." *American Journal of Science,* 305, 467-502. There is also evidence that Archaea metabolized large amounts of iron: Johnson, C.M.; Beard, B.L. and E.E. Roden (2008). "The Iron Isotope Fingerprints of Redox and Biogeochemical Cycling in Modern and Ancient Earth." *Annu. Rev. Earth Planet. Sci.* 36, 457–93. The likely metabolic pathways include the Wood-Ljungdahl pathway of acetogenesis, which uses Ni and Co enzymes. [Ragsdale, S.W. and, E. Pierce. (2008) "Acetogenesis and the Wood–Ljungdahl pathway of CO2 fixation." *Biochimica et Biophysica Acta* 1784, 1873–98.] "This [genetic evidence] suggests that the last common ancestor of all life also metabolized hydrogen for energy at high temperatures. … The more ancient theme of lithotrophy [more ancient that organotrophy, that is!], metabolism of inorganic compounds, is also widely distributed phylogenetically, intermixed with organotrophic organisms. The pattern suggests that organotrophy arose many times from otherwise photosynthetic or lithotrophic organisms. Indeed, many instances of Bacteria can switch between these modes of nutrition." [Norman R. Pace (1997). "A Molecular View of Microbial Diversity and the Biosphere." *Science* 276, 734-740.]

[112] Methane ultimately draws its energy from sulfides from the interior of the earth. [CoE p.210.] For example, the oxidation of glucose to carbon dioxide and water gives 2870 kJ/mol of energy while the conversion of glucose to methane and carbon dioxide gives only 390 kJ/mol. [Schink, B. (1997). "Energetics of Syntrophic Cooperation in Methanogenic Degradation." *Micro. Mol. Biol. Reviews*, 61 (2), 262-280.] Interestingly, the methane produced may have not warmed the earth too much because of production of a "methane haze" that kept the earth cooler. [Kasting, J.F. and J.L. Seifert. (2002). "Life and the Evolution of Earth's Atmosphere." *Science* 296, 1066-7.]

[113] "The small amount of energy available in methanogenic conversion forces the microorganisms involved into a very efficient cooperation." [Schink, B. (1997). "Energetics of Syntrophic Cooperation in Methanogenic Degradation." *Micro. Mol. Biol. Reviews*, 61 (2), 262-280.] One of the advantages to this particular chemical story is that it emphasizes importance of cooperation rather than competition. [See CoE p.271.] Such symbiotic cooperation is both historically important (leading to mitochondria and chloroplasts) and is important in the ecological communities such as the rain forest, in which a nitrogen-fixing symbiont actually lives in the fungus gardens tended by leaf-cutting ants – layer upon layer of cyclic cooperation, which according to this chemical story, *entropy* promotes! [Pinto-Tomas, A.A. *et al*. (2009). "Symbiotic Nitrogen Fixation in the Fungus Gardens of

cooperation is an alignment of organisms that can "resonate" and produce something new in combination![114]) Methane is a great starter food but by itself can only support simple life.[115] Also, it was part of the limited amount of "free food" provided by the early earth – so it was running out.[116]

Leaf-Cutter Ants." *Science* 326 (5956), 1120 – 1123.] Life is often defined as competition but this shows how it can be defined as cooperation as well: "Lord Tennyson might just as well have cast nature as 'green in stem and leaf.'" [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 191.]

[114] "Divided, the fungal gray and photosynthetic green components of a lichen look nothing like one another. Nor does either member resemble their extraordinary opposite. The result of symbiosis, far from being predictable by simple addition, is a noncumulative surprise." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 146.]

[115] Microorganisms prefer light carbon to a chemically heavier version, and 2.75 billion year old rocks show high amounts of light-carbon methane, like the entire planet was a methane seep. [Susan M. Gaines, Geoffrey Eglinton and Jurgen Rullkotter. (2008). *Echoes of Life: What Fossil Molecules Reveal about Earth History.* Oxford Univ. Press. p.255] The methane ecosystem may even have been optimal given the lack of oxygen, but an oxygen-reacting ecosystem is much more powerful. [CoE p.236.]

[116] Both sugars and hydrogen would be this "free food." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 78.]

Little bubbles of life reduced their insides, inadvertently oxidizing the environment, with oxidized waste but not yet oxygen itself. Pure oxygen at first was a poisonous "pollutant"[117] that would have killed the ecosystem by oxidizing its reduced-carbon food, destroying it.[118] Rather, oxygen combined with metals and sank to the ocean floor as iron oxide rust.[119] (When you mix iron nitrate with sodium hydroxide you get a similar orange iron hydroxide precipitate.) This is the first breath of oxygen, the regular stripes reflecting the yearly summer bloom and winter sabbatical of cyanobacterial growth, a regular annual metronome marking out the tempo of oxygenation.[120] This process had to be excruciatingly slow because the entire earth had to be oxidized,[121] and organisms only changed by slowly rearranging DNA 's sluggish covalent bonds. No wonder it took billions of years.[122]

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[117] CoE p.235, 279. "Many modern prokaryotes still function best at oxygen levels of about ten percent – half the atmosphere's typical concentration today." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 105.]

[118] "If we are correct in thinking that in the most primitive times carbon was readily available as CO, nitrogen as NH_3 and HCN and sulfur as H_2S, also a source of hydrogen, then the oxidation of the molecules by oxygen to CO_2, N_2, oxides of nitrogen and sulfur and H_2O, with increasing O_2, was potentially a slowly increasing disaster for anaerobes." [CoE p.247.] The hydrogenation of CO_2 to formaldehyde and water is about twice as hard at the hydrogenation of CO to formaldehyde (think of it as having to reduce that extra oxygen).

[119] Picture on left is of Banded Iron Formations (BIFs). [http://www.nature.com/nature/journal/v458/n7239/] The bands probably come from the summer/winter cycles of biological growth. [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York.]

[120] Gererd Eskelin describes the "beat" as regular events that must recur in groups of two or three, leading to four basic kinds of rhythm. The regularity of the BIF spacings is, by his definition, a truly musical rhythm.

[121] CoE p.194. Because of its replicating nature, life has the potential to change a planet: "A single photosynthetic blue-green bacterium growing and dividing under ideal conditions could, in theory, produce all the oxygen now in the atmosphere in just a few weeks." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 72.]

[122] "It would appear that it took some 3 to 2 billion years to remove most of this ferrous iron and sulfide from the sea." [CoE p.332] The UV protection of the cyclic reactions in the ozone layer has only been present for 500 million years or so. [CoE p.333] Oxygen was trash, but it held treasure. As the movie *The Fisher King* quotes: "You find some wonderful things in the trash."

We have a chemical paradox here, in that oxygen is both the dangerous enemy of life, and its inexorable chemical destiny. The nickel-and-methane-based ecosystem was in trouble, having no use for oxygen but producing it constantly. Even worse, its hydrogen food was steadily being driven away by the solar wind. At this very moment lava temperatures dropped, and nickel levels dropped at the same time, suggesting the planet cooled off below nickel's freezing point, so it disappeared inside the earth.[123] The ocean soon ran out of nickel.[124] This "nickel famine" forced the methane ecosystem to retreat into the nickel-rich, oxygen-poor corners of the earth.[125] In *The Fellowship of the Ring*, the adventurers float past massive statues, relics of a lost world. Ancient methane-producing proteins are also relics, echoes of a biochemical lost world.[126] They built their ecosystem on the shifting sand of nickel availability. When the rains fell and the earth cooled, their foundation was swept away.

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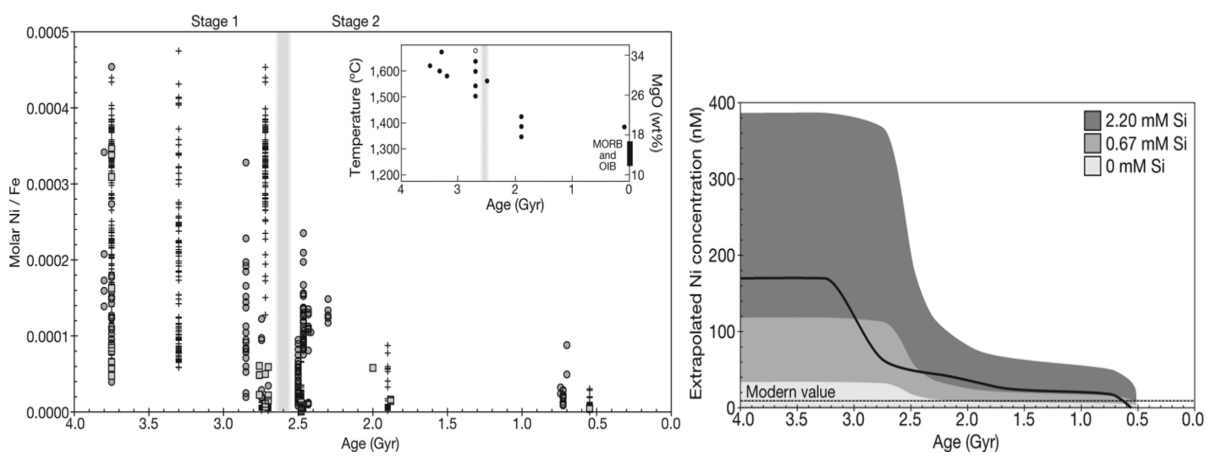
[123] Why did this happen at this precise point? Either it is a cosmic coincidence, or there is some deep connection between nickel's melting point and its use for methane metabolism that I do not understand. Either way, the loss of nickel appears to have happened at a good time for complex life to fill the ecosystem.

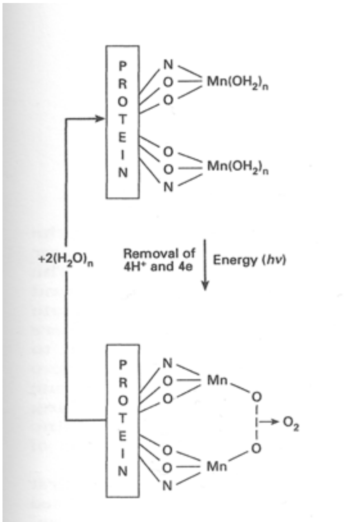
[124]



Konhauser, K.O.; Pecoits, E.; Lalonde, S.V.; Papineau, D.; Nisbet, E.G.; Barley, M.E.; Arndt, N.T.; Zahnle, K. and B.S. Kamber. (2009). "Oceanic nickel depletion and a methanogen famine before the Great Oxidation Event." *Nature* 258, 750-3.

[125] Such as in the nickel-rich cellulose-degrading bacteria in ruminant stomachs [CoE p.328] or the arachaea that produce natural-gas methane in the earth's crust. Most Archaea are lithotropic and rely on hydrogen. Even those that live at high temperatures and exhale H_2S are closer genetically to us than the typical *E.coli* bacterium – in that sense, an archaean would be our strange uncle, and that the earth is full of strange uncles. "There is increasing evidence that the crust of the earth is *shot through* with biomass, wherever the physical conditions permit." [Emphasis mine to highlight the similarity to the great poem "Bright Wings" by Gerard Manley Hopkins.] [Norman R. Pace (1997). "A Molecular View of Microbial Diversity and the Biosphere." *Science* 276, 734-740.]

[126] We are as big relative to these ruins as those statues were to the hobbits, so even the difference in scale is similar, if inverted.



Song Six: From Sulfur to Oxygen, starring "Photosynthesis." In the wake of the Great Nickel Famine, the slate was cleared for innovation. One organism held a strange metal on its outside surface, manganese, which allowed it to run on just sunlight and electrons from water.[127] Manganese is the only soluble ion on Earth that exists in charge states of +4 to +6.[128] Two manganese atoms may hold two waters together, and light energy could revert the water to hydrogen plus electrons (pushed inside the cell) and oxygen (outside the cell).[129]

This is a separation of charge driven by the sun, the core of photosynthesis.[130] If the hydrogen and electrons are kept inside and the oxygen is pushed outside as waste, the insides are reduced and the outsides are oxidized, but, crucially, this process is now powered by the sun and is better at capturing energy,[131] driving the entropy cycle ever faster.[132] Photosynthesis

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[127] Actually, there were probably two such organisms that collaborated and produced the two-photon system we see today.

[128] On the exterior of the cell in pre-formed calcium binding sites. [CoE p.48 Figure 2.6.] "It is doubtful if any other element could carry out this reaction, since it has the accessible oxidation states required … " [CoE p.220.] Mn^{2+} is similar enough to Ca^{2+} that it would have been rejected by the same mechanisms, and also would form structures on the surface of the cell cross-linked by oxygen for similar chemical reasons. Because it had the hidden ability to reach higher oxidation states, it was then positioned to perform its oxidative chemistry with water. In this manner a Mn-containing oxidase can be designed from just adding Mn-binding residues to a light-catching reaction center. [Thielges, M.; Uyeda, G.; Camara-Artigas, A.; Kalman, L.; Williams, J.C.; and J.P. Allen. (2005). "Design of a Redox-Linked Active Metal Site: Manganese Bound to Bacterial Reaction Centers at a Site Resembling That of Photosystem II." *Biochemistry*, 40 (22), 7389-94.] Today the manganese cube in plants (still?) includes a single calcium! [CoE p.221.] Daniel Nocera can use Co for his "synthetic water-splitting electrode" because he can make it available; but Co was and is not available to the ecosystem as a whole in high enough concentration for this to develop, and life must use Mn instead. [See CoE Table 1.7]

[129] See figure on left, from Williams, R.J.P. and J.J.R. Frausto da Silva (1999). *Bringing Chemistry to Life: From Matter to Man*. Oxford University Press, p.389.

[130] CoE p.63.

[131] Partly because getting electrons off water is very hard, requiring two photons, and therefore this is an expensive process. The good news is sunlight is abundant and comes from outside the system.

[132] As Arnold of Villanova suggested, sun does transmute carbon dioxide into fixed carbon sugars in the grape, and so wine is captured sunlight (or at least its carbon-carbon bonds are). The process probably started with the easier-to-oxidize H_2S providing electrons (requiring only a single photon for electron removal), like in green sulfur bacteria. The same bacteria may have pioneered efficient visible light capture with green magnesium in a porphyrin box (the same box that serves as an interchangable "life-ring" for Fe, Co, and Ni!), making chlorophyll. [See Figure 5.2 CoE p.199.] Purple bacteria using higher-energy light could combine with the green bacterial

depends on two unique metals: magnesium in chlorophyll catches light and manganese rips water apart. If manganese wasn't in the periodic table, would photosynthesis be possible?[133]

Once the sun drove oxygen generation, the atmosphere oxygenated in an upward (if jagged) slope throughout natural history.[134] More than a dozen different pieces of evidence combine to show historical oxygenation.

We can know which elements bound oxygen first as its concentration increased using a chemical tool called redox potentials. On this wheel of potentials, start here at a slightly reducing environment (-0.2V),

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system to make two photosystems that together had enough punch to fix CO_2 directly from the atmosphere and to split water at the same time. [CoE p.213.] Water is especially good as a solvent for life; not only does it provide liquid flow at high temperatures, but it also hides the supremely reactive oxygen inside itself for photosynthesis to crack open and the rest of the ecosystem to use. [CoE p.214.] Other proposals of formaldehyde or other solvents for life must find a similar source of chemical energy highly available in the environment, and there is simply not as much chemical potentiality hidden in formaldehyde because it is half carbon.

[133] Daniel Nocera is a chemist who saw this system and was inspired by it to invent an electrode for reacting sunlight with water. Most chemists tried various bizarre metals or organometal complexes to develop a water-splitting reaction, but the reactive oxygen would corrode and destroy any successful electrode. Nocera reasoned that plants have this same problem, but instead of searching for a structure that will not break down, plants take out the old, battered enzyme and put in a new one every 30 minutes. So Nocera designed an electrode that was self-healing like the plant, and so far it is perhaps the most promising application of solar energy yet. Once there is a patent for this process, a plant should be co-author.

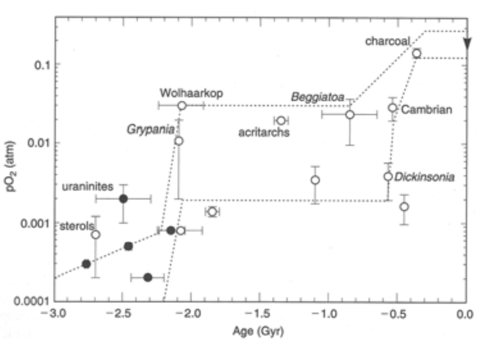
[134] 

Figure 3.2 Geochemical and biological constraints on atmospheric oxygen over the past 3 billion years. Filled circles are estimated upper limits on oxygen. Empty circles are estimated lower limits on oxygen. The inverted triangle indicates the present partial pressure of oxygen. Age error bars indicate uncertainty in dating or the range of ages over which sediments were deposited. Partial pressure error bars indicate uncertainties in the estimates. The dashed lines are approximate upper and lower bounds on atmospheric oxygen. Unlabelled points are all paleosols (ancient soils that were exposed to the atmosphere) – see text for details.

From "The coupled evolution of life and atmospheric oxygen" by Timothy M. Lenton in *Evolution on Planet Earth* (2003) Ed. By Lynn J. Rothschild and Adrian M. Lister p.40. See also Sessions, A.L.; Doughty, D.M.; Welander, P.V.; Summons, R.E.; Newman, D.K. (2009). "The Continuing Puzzle of the Great Oxidation Event." Current Biology *19*, R567–74. "The rays of the sun … have completely transformed the face of the earth." [Vladimir Vernadsky quoted in *What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 158.]

then shift to today's oxidizing environment as photosynthetic oxygen waste changed the world.[135] The lines are constant redox potentials set by the periodic table, constraining when chemicals changed. As lines are crossed that particular chemical binds oxygen (or releases hydrogen). We see, for example, that nitrogen lost hydrogen -- ammonia became dinitrogen gas, harder to use but less toxic. Likewise, hydrogen sulfide became oxidized sulfate, so sulfide was harder to find. Many of these changes made life harder at first, because oxidized forms are less reactive,[136] and this forced microorganisms to innovate. Soon they accomplished amazing chemical feats such as cracking the triple bond of nitrogen in two or eating sulfate instead of sulfide.[137] Also, the new detection systems for first avoiding oxidized poisons and then seeking out new forms of food meant that life had more information about its environment; it could "see" more clearly.[138]

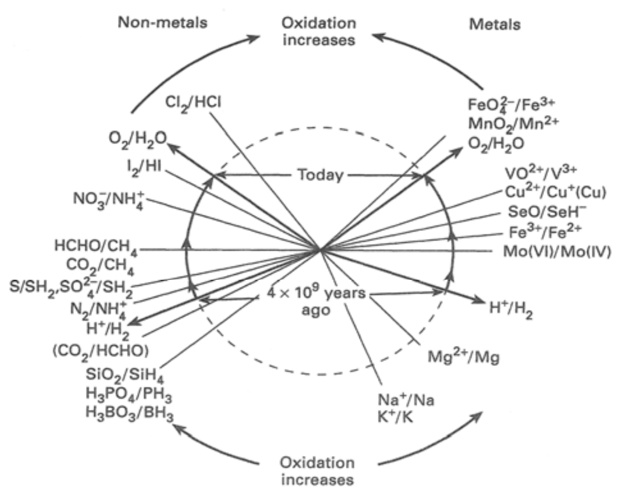


Fig. 6.16 The sweep of rising redox potential at pH = 7.0 with the evolution of Earth's surface showing changes imposed on metals from lower to higher positive oxidation states and on non-metals from higher to lower negative oxidation states.

[135] Williams, R.J.P. and J.J.R. Frausto da Silva (1999). *Bringing Chemistry to Life: From Matter to Man*. Oxford University Press, p.189.

[136] Hydrogen, methane, and ammonia were oxidized away and could not be used as common fuels anymore, except in small corners of the biosphere. [CoE p.28.] "Thus the changes in the environment were a burden at first leading to a gain later." [Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, p.334]

[137] [Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, p.337]. These organisms can be organized according to their redox ranges of activity to show that the sulfate and nitrate-using microbes are intermediate in this parameter as well as in age between anaerobes and aerobes. [Table 6.3 CoE p.243.] A similar chart shows how redox activity tracks with sequential use of metals in history (iron age, etc.). For both evolution and culture, history correlates with chemistry. These tiny chemists are also "unseen angels" that allow necessary recycling of matter, breaking it down and producing heat, all for an efficient cycle.

[138] CoE p.266. Possibly even more than "in a sense," since the vision protein we see with (rhodopsin) was first used at this time by microorganisms for purposes unrelated to vision. See footnote in Song Seven.

We can see what happened next from the chemical patterns of which metals advanced cells use that simpler cells do not. One clue is the hundreds of zinc proteins used for advanced biological processes.[139] Zinc is a "slow"-binding ion,[140] best for slow processes in advanced organisms that take years rather than days to grow.[141] For example, human zinc deficiency causes delayed puberty, a DNA-mediated advanced developmental process.[142] If you boost your immune system with Zicam, you are dosing yourself with extra zinc to enhance that advanced system. A 2006 quantitative genomic analysis found that advanced cells (the blue bars) use more zinc-binding proteins, while simpler cells use more iron, cobalt, and manganese proteins, three ions much more abundant in the ancient sulfide ocean.[143] A similar 2008 genomic analysis found cells have used copper only recently.[144] Additionally, nearly all molecules used

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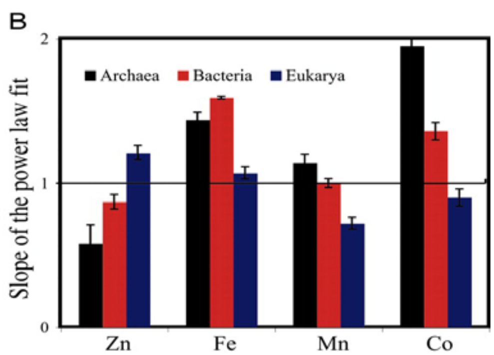
[139] Eukaryotes use the "later" elements Cu and Zn to neutralize oxygen; prokaryotes use Fe and Mn, which dissociate more readily and are suboptimal, indicating their early origin. [CoE p.292.]

[140] It is also "safe" with no redox activity. This is because zinc is at the end of the transition metal block and its 3d electron shell is completely full, no room in the inn for more electrons. [CoE p.295; also see earlier classification of transition metals.]

[141] CoE p. 72 Table 2.12. Also CoE p.186 for lifespans. "In higher animals … between 1 and 5% of DNA expression is now controlled by … zinc proteins." [CoE p.338.] Zinc fingers that bind and *edit* DNA are being proposed as a wide-ranging and potent therapeutic [Wade, N. (December 28, 2009). "In New Way to Edit DNA, Hope for Treating Disease." *New York Times.*]

[142] This condition can be cured with a simple chemical – zinc sulfate – added to food. Likewise, manganese is required for milk production. This complex spectrum of differentiation in animals and especially mammals may be part of why it is easy to clone plant cells but hard to clone animal cells. [CoE p.330.]

[143] 

The power law slopes describing the abundances of Fe-, Zn-, Mn-, and Co/B_{12}-binding structural domains in the proteomes of Archaea (black), Bacteria (red), and Eukarya (blue). [Dupont, C.L.; Yang, S.; Palenik B.; and P.E. Bourne. (2006). "Modern proteomes contain putative imprints of ancient shifts in trace metal geochemistry." *Proc. Natl. Acad. Sci.,* 103(47), 17822-7.] Also see the earlier metal-requirement study of Quigg, A., et al. (2003). "The evolutionary inheritance of elemental stoichiometry in marine phytoplankton." *Nature*, 425, 291-4.

[144] Ridge, P.G.; Zhang, Y.; V.N. Gladyshev. (2008). "Comparative Genomic Analyses of Copper Transporters and Cuproproteomes Reveal Evolutionary Dynamics of Copper Utilization and Its Link to Oxygen." *PLoS ONE* 3(1): e1378. doi:10.1371/journal.pone.0001378. In fact, metal availability corresponds with, and may even cause,

for intercellular communication in advanced cells are old molecules, modified with an oxygen or two by zinc or copper enzymes;[145]and oxygen (but not sulfur or selenium) is used in nearly all structures that stick two advanced cells together.[146] For example, oxygen links together lignin in wood.[147] In animals, oxygen forms connections between and around cells, chitin in insects and collagen in us (broken down by – you guessed it -- zinc enzymes).[148] All this happened because as oxygen increased, zinc and copper were unlocked from sediments because their oxides dissolve better than their sulfides.[149] Iron however

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evolution of new protein architectures, see Ji, H.F.; Chen, L.; Jiang, Y.Y.; and H.Y. Zhang. (2009). "Evolutionary formation of new protein folds is linked to metallic cofactor recruitment." *BioEssays*, 31(9), 975-80.

[145] Because oxidized molecules were rejected, they provided information from the inside for cells on the outside. [Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, 335.] For example, adrenaline communicates the fight or flight response, and it is made outside the cytoplasm by reacting an old molecule with oxygen, using a copper-containing enzyme. [Williams, R.J.P. and J.J.R. Frausto da Silva (2008) "Evolution revisited by inorganic chemists." In *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning*, edited by John D. Barrow, Simon Conway Morris, Stephen J. Freeland, and Charles L. Harper, Jr., Cambridge Univ. Press, p.471.] Zinc shows up here, too, coordinating the messages and acting as a "master hormone." [CoE p.344.] The important cancer protein p53, is a zinc message-coordination protein that is often mutated in cancer; in general, intercellular messages are switched off by zinc or copper enzymes. [CoE p.349.] Zinc is used in peptidases; copper in oxidases that inactivate aromatic amines.

[146] The early algae coating, algaenan, uses oxygen to bridge the polymer, forming a molecular Ziploc coating around the algae that let it colonize the land, leading to land plants. This may have required cooperative symbiosis as well. Some scientists "contend that successful colonization of the land by the ancestors of modern land plants would have been impossible without root fungi." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 148.] Finally, innovations in the capture of water and control of flow were what allowed plants to survive outside of the aqueous womb of the ocean; the early plants called bryophytes not as good as later plants at this flow control. [*ibid* p.161-7.] The resulting "greening of the earth" may have caused oxygen levels to jump. [Knauth, L.P. and M.J. Kennedy (2009) "The late Precambrian greening of the Earth," *Nature* 460 p. 728-32.] It has also been suggested that green algae were ejected from the ocean because they used the oxygen-related elements (iron, copper, and zinc) available in the shallows while the deep ocean was still oxygen-starved, so they were able to pack up and colonize the dry land, leaving the ocean to the sulfur-compatible manganese- and cobalt-using red algae. [P.G. Falkowski, *et al.* (2004). "The Evolution of Modern Eukaryotic Phytoplankton." Science, 305 (5682), pp. 354-60.]

[147] Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, 339.

[148] Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, 341. The less-advanced chitin and lignin are laid down once and "die," but collagen is continuously remodeled and therefore more "alive" and responsive to change. Cancer cells eject zinc proteases that cut these tethers and lead to metastasis. [CoE p.354.] Then oxygen-cutting enzymes cut cells free for motion or metastasis, using copper, *outside* the cell.

[149] We replicate this ancient reaction when we release these metals from sulfide ores by heating them in the presence of oxygen. [See CoE p. 404-405.]

became scarce because its oxide is insoluble – it fell, solid, to the ocean floor, its “voice” faded from the environment, and intense competition for its unique chemistry began.[150]

It took a long time to oxygenate the system – after all, the entire earth was reduced -- but this is good because oxygen is so reactive it will destroy unprotected cells.[151] Life had to take the equivalent of Harry Potter’s “Defense Against the Dark Arts” class -- “Defense Against Oxygen.” Life hid away from oxygen molecules in the ocean, which was an oxygen-free zone because oxygen does not dissolve in water and iron removed it as rust.[152] When chemical defenses developed, they were built from oxygen-reactive metals: first iron, then copper and zinc. [153] When oxygen stuck to an iron protein, the cell would defend itself by ejecting the oxidized protein and making more. [154] But if some innocent bystander molecule was next to the iron, the oxygen could transfer to the bystander, solving all sorts of problems. The oxygen was neutralized, the protein didn’t have to be thrown out, and the cell had a bonus new oxygenated molecule. So waste oxygen would start to build new things.[155] One example: oxygen plus sterol makes cholesterol, which dissolves in membranes, making them more flexible and bigger, allowing cells to grow big enough to subsume others, and even to grow filaments. Oxygen makes cholesterol which makes for “better use of space”[156] and better energy capture.

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[150] Cadmium, mercury and lead are also more soluble as oxides than sulfides, but they are harder to oxidize and arrive late in the ocean, so late that life never learned to use them, making them poisons. [Williams, R.J.P. and J.J.R. Frausto da Silva (2003) “Evolution was Chemically Constrained.” *J. Theo. Biol.* 220, p.339]

[151] CoE p.28.

[152] The absence of oxygen is confirmed by ancient carbon skeletons from purple synthetic bacteria, which oxygen would have destroyed, observed in ocean sediments from this era. [Susan M. Gaines, Geoffrey Eglinton and Jurgen Rullkotter. (2008). *Echoes of Life: What Fossil Molecules Reveal about Earth History.* Oxford Univ. Press. p. 253]

[153] Today advanced cells defend against oxygen radicals with antioxidant copper and zinc enzymes. Simple chemicals like vitamin E also act as general antioxidants, neutralizing stray oxygen radicals. [Lenton, T.M. (2003). “The coupled evolution of life and atmospheric oxygen” in *Evolution on Planet Earth* (2003) Ed. By Lynn J. Rothschild and Adrian M. Lister, p.43.]

[154] All three metals have been observed with this function in prokaryotes. [CoE p.246.] For example, humans and mice have a transport protein aquaglyceroporin (AQP-9) that exports arsenic from cells. [Carbrey, J.M. *et al*. (2009). “Reduced arsenic clearance and increased toxicity in aquaglyceroporin-9-null mice.” *Proc. Natl. Acad. Sci*., 106(37), 15956-60.] NADH can also directly combine with oxygen to neutralize it to water. [CoE p.246.] By making a chain between the two molecules, an entire electron-transport chain can be built. Truncated electron-transport chains are observed in bacteria.

[155] For biochemical details on how this may work, see Hewitson, K.S.; Granatino, N.; Welford, R.W.D.; McDonough, M.A.; and C.J Schofield. (2005). “Oxidation by 2-oxoglutarate oxygenases: non-haem iron systems in catalysis and signaling.” *Phil. Trans. Royal Soc. A*, 363 (1829), 807-28.

[156] Quote from CoE p.362. See also Williams, R.J.P. and J.J.R. Frausto da Silva (2003) “Evolution was Chemically Constrained.” *J. Theo. Biol.* 220, 338. For the disadvantages of the pre-cholesterol cell membrane see CoE p.271.

After cholesterol, cells could grow big enough to enclose their own subcellular bubbles. The most important subcellular bubble exploits the fact that environmental oxygen was "a huge energy store."[157] Organisms started to use this reactive oxygen waste to degrade chemical bonds to heat, advancing the cycle of life. Oxygen plus sugars makes CO_2 gas (easily breathed out) with energy left over, a reaction 10 times more efficient than breaking sugar down without oxygen.[158] Then oxygen is no longer a waste, but a source of energy in an energy- and entropy-producing cycle.[159] Oxidizing chemistry is still dangerous today, spinning out half-reacted "reactive oxygen species" that wreck the surroundings. For its own protection, the cell had to keep oxidative machinery in its own bubble.[160]

Lots of bubbles can do lots of different chemistries. The "carbon-burning" mitochondrial bubble[161] is the cell's engine; the digestive lysosome bubble its dining room; the peroxisome its chemical "fume hood"; the nucleus its library; endosomes and vacuoles, its storage sheds.[162] Different compartments have

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[157] CoE p.136.

[158] Schink, B. (1997). "Energetics of Syntrophic Cooperation in Methanogenic Degradation." *Micro. Mol. Biol. Reviews*, 61 (2), 262-280. "Whereas on average two molecules of ATP are produced by fermentation of a sugar molecule, with the evolution of respiration the same sugar molecule was made to yield as many as thiry-six ATP molecules." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 105.]

[159] Because the carbon material was previously alive, this means oxygen plus death equals spread-out energy, heat and entropy increase. [CoE p. 235.] All available oxygen produced on land is used up by mitochondrial oxidation and does not cause a net oxidation of the environment, but because some reduced organic material is sequestered to ocean sediment, there is a net production of oxygen from ocean microbes. This is another reason why the oxidation of the environment took so long. [See Kasting, J.F. and J.L. Seifert. (2002). "Life and the Evolution of Earth's Atmosphere." *Science* 296, 1066-7.]

[160] (And to avoid the reducing cytoplasm.) More likely, an archaeal cell co-opted an existing bacterial bubble that replicated itself symbiotically and became our mitochondria, a cooperative (not competitive!) process. [Norman R. Pace (1997). "A Molecular View of Microbial Diversity and the Biosphere." *Science* 276, 734-40.] It is ultimately more efficient for the cell to keep this process under control in its own membrane because it allows for the producing of more energy-capturing and energy-degrading cells, and therefore a higher overall entropy rate. [See CoE p.254.] In fact, symbiosis and gene-mixing probably runs deeper than we currently imagine: "The *Chromista*, a group of diatoms, have DNA traceable to four different organisms – their own as a green algae, from red algae, from purple bacteria and from cyanobacteria, many concerned with their organelles." [CoE p.287.]

[161] Probably produced by some kind of bubble-joining activity of life (digestion or infection) in which a cyanobacterium became part of an archaeon through endosymbiosis. "Genetic evidence, DNA, RNA, and protein sequence information links red algal plastids to certain cyanobacteria with the same forensic accuracy admissible in court to convict a rapist whose DNA matches that of a sperm sample." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 109-110.] The citric acid cycle of reactions that powers the mitochondria may also be chemically optimized and inevitable. [Smith, E. and H.J. Morowitz. (2004). "Universality in intermediary metabolism." *Proc. Natl. Acad. Sci.* 101 (36), 13168-73.]

[162] CoE p.288. For some metal ion usage differences see CoE p.289 Fig 7.5. These compartments are little bubbles of "outside" that are inside the cell: for instance, pumps that normally point outside point from the cytoplasm into

different chemistries with such different metal concentrations that they are *colored* differently.[163] Life works better like this, capturing more energy and producing more heat (so the Second Law made it happen)[164] and the Earth bubbled with life.

Soon entire cells started to specialize[165] and join together with oxygen bridges. These formed *organs* and *organ*-isms. Once cell was connected to cell, cholesterol fossils tell us that multicellular simple sponges -- animals that eat but do not move -- first abounded in the deep oceans, filtering huge amounts of seawater and clearing it of decayed organic material.[166] This cleaned up the oceans at last. Oxygen

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these vesicles. [CoE p.290] ; and for each of these rooms a different chemistry could be adopted, with "special ways of handling metal ions in compartments."

[163] CoE p. 344. Muscle cells will be red or white depending on specialization, as plant cells will be white or green depending on root or leaf: and a root cell will become green in the light! (Repeated calcium pulses will switch a muscle cell's color as well.)

[164] Compartments are fundamentally necessary because life needs to chemically build up at the same time that it chemically breaks down, and the only way to do that is to have different bubbles for each process: organelles. [CoE p.311.] The complexity came at a cost: "slower rates of reproduction due to complexity of organisation and slower adaptability. The difficulties of organisation are relieved somewhat by removing the need to produce all essential basic chemicals and by more extensive controls." [CoE p.311.] (In other words, by developing vitamins and off-switches.)

[165] Starting with simple differential in cyanobacteria and nitrogen fixation. [CoE p.264.]

[166] [Susan M. Gaines, Geoffrey Eglinton and Jurgen Rullkotter. (2008). *Echoes of Life: What Fossil Molecules Reveal about Earth History*. Oxford Univ. Press p.251.] The carbon skeleton is a form of cholesterol (isopropylcholesterol). These sponges are as stationary as plants but mobility developed to allow finding more sources of food, and more senses developed to detect sources of food.

saturated the depths, and an explosion of animal life followed.[167] Oxygen went from rejected toxin to source of life, from waste to cornerstone, like a little leaven will spread throughout a loaf, growing and expanding from year to year, providing natural history with a directional arrow.

Oxygen follows a logical progression, from poison, to rejected waste, to useful in a separate compartment, to making hormones that mediate communication between compartments.[168] Chemically speaking, oxygen was so reactive it had to be rejected as a poison at first, but this same reactivity eventually made it central. The molecule that the builders rejected became the cornerstone. No human made up this oxygen story; it was given to us, discovered through reason, and it has a familiar shape, a narrative, musical logic -- just not so much "boy meets girl," as "organism meets environment."

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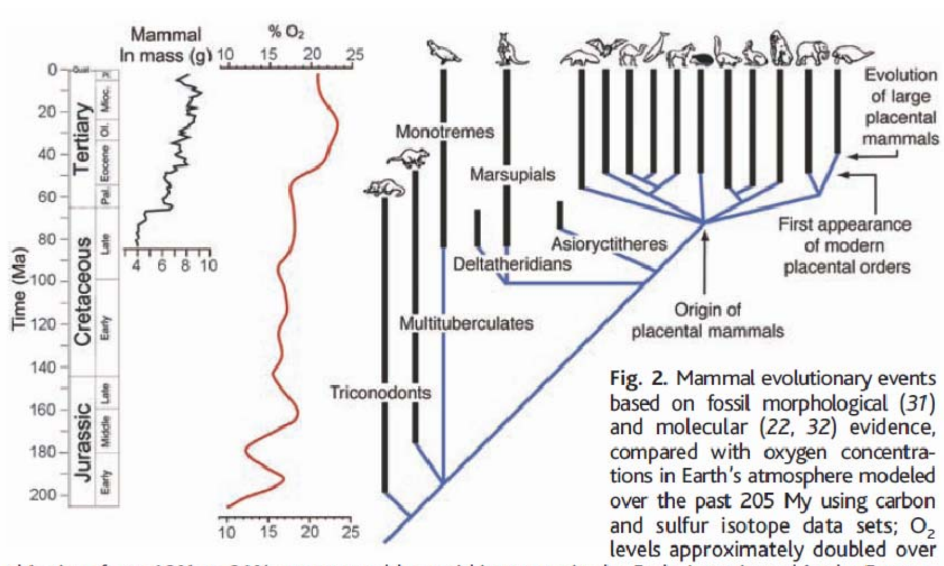
167 

Fig. 2. Mammal evolutionary events based on fossil morphological (*31*) and molecular (*22, 32*) evidence, compared with oxygen concentrations in Earth's atmosphere modeled over the past 205 My using carbon and sulfur isotope data sets; O_2 levels approximately doubled over this time from 10% to 21%, punctuated by rapid increases in the Early Jurassic and in the Eocene. Changes in average mammalian body mass is taken from (*27*). Vertical black bars represent known fossil ranges, blue lines represent inferred phylogenetic branching. Only some of the ordinal-level placental mammals are shown.

Oxygen is such a powerful chemical that increases in oxygen may correlate with speciation, with increased animal size (from mouse to man), and even with the creation of placentas, all in step with oxygen increases. [Paul G. Falkowski, *et al.* (2005). "The Rise of Oxygen over the Past 205 Million Years and the Evolution of Large Placental Mammals." *Science* 309, 2202.]

168 (or more simply: "poison → protection → use.") [CoE p.292.] An "epigenetic environmental mechanism" for how a toxic chemical can cause enhanced mutation involves histones: a frequently damaged gene is transcribed more often, meaning it necessarily is removed from the protection of the histone and exposed to the environment. There that particular stretch of DNA is more prone to damage, mutation, or duplication. [CoE p.308.] This kind of system could even work without histones with the damaging initial poison being light, damaging the gene and requiring its frequent (and random) repair. [CoE p.445.]

Song Seven: From Oxygen to Humans, starring "the Brain."

Finally, an organ specialized for information storage developed, its very chemistry based on gradients, malleable and educable: the brain.[169] Neurons are normal cells that have *repurposed* old biochemical flows. Physiologist Denis Nobel wrote that "the proteins and other molecules that form the brain are hardly different from those we find in the rest of the body. Most often, they are identical. And the differences, when they occur, are not particularly mysterious."[170] The crucial innovation that led to neurons was a hole: a protein hole in the membrane selective for sodium; open the hole, and the chemical pressure pushes sodium in. (Recall that back in Song Five cells started to eject sodium, and now all that work can be put to good use!) Sodium creates a charged, fast, electrical pulse because it both binds and lets go the most quickly of all ions.[171] Because potassium was previously pumped in, another hole for potassium lets its positive charge out, resetting the neuron to normal charge.[172] However, sodium and potassium cannot end the pulse: they are fast but too weak to change protein shapes. A different ion is needed, which must be abundant outside the cell, fast-on but *slow*-off. Calcium

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[169] It also allowed some organisms to move around from plant to plant, collecting and degrading both the oxygen and the sugars the plants produced and therefore turning the cycle of entropy production: animals, or "scavengers *par excellence.*" [CoE p.324.] This had to happen because "it is difficult to conceive of a highly mobile plant, a light harvester." [CoE p.386.] Two kinds of organisms turn the cycle: collectors of light that store sugar, and collectors of sugar that emit heat. Animals therefore needed to know their environment well to move to the places with most food, and developed highly adapted senses as a result. DNA works as information storage, too, but only between generations, encumbered with stable but sluggish covalent bonds. As organisms' lifespans lengthened and skins thickened, DNA's influence waned. To compensate, a group of specialized cells interconnected, starting with sea slugs and flat worms. [CoE p.325.] The resulting neurons have more diversity than DNA, with 20 concentration-dependent neurotransmitters and ions instead of 4 nucleobases. [Williams, R.J.P. and J.J.R. Frausto da Silva. (2008). "Evolution revisited by inorganic chemists." In *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning*, edited by John D. Barrow, Simon Conway Morris, Stephen J. Freeland, and Charles L. Harper, Jr., Cambridge Univ. Press, p. 475.]

[170] Noble, D. (2006). *Music of Life: Biology Beyond the Genome.* Oxford Univ. Press, p. 119. The key to specialization may be gene duplication, because gene duplication allows parallel isozymes to co-exist and then diverge depending on development and differentiation. [CoE p.297.]

[171] This is bad for building structure but good for sending a fast signal. Song Five described a disproportionation by which all cells ship out sodium and ship in potassium, so that a "high pressure" of sodium is outside the cell, perhaps explaining why you should worry more about sodium intake than potassium. This disproportionation began in the ancient ocean but continues in animals as the blood outside cells, which is a salty substitute for the ocean, portable and chemically controlled. [CoE p.335.] Calcium and oxygen linkages are also chemically prominent in the blood and it is considered "exterior" to the cytoplasm, which is still reduced and calcium- and oxygen-poor. [CoE p.336; p.53 Fig 2.7.]

[172] Negative chloride ions balance the charges.

was ejected in Song Five,[173] it has twice the charge for extra protein-pushing power, and it operates on the slow millisecond timescale, matching the movements of proteins.[174] Short calcium pulses at the very end of the neuron unlock neurotransmitters,[175] making your memories from calcium.[176] These chemical characteristics mean calcium is used universally as a pulsed communicator between compartments.[177] The higher up the organization chart of life you go, the more calcium proteins you see.[178] Williams and da Silva write, "[Life] *had* to discover the value of this calcium chemistry … . It was not just a matter of random mutation but of opportunity meeting necessity as this was an inevitable advance if optimal

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[173] Calcium binds quickly because it is small, but it is slow-off because it has two plus charges, and it is a safe, non-redox element so it can act alone. Mg is similarly "safe" and divalent, but is not used for communication because it was already busy; its weaker binding to oxygen (but still observable) means it was picked to be used in conjuction with ATP (it is also a bit too slow kinetically). CoE p.303.

[174] $K=10^7\ M^{-1}$. [CoE p.71.] In fact, calcium's tight binding explains why Boston Baked Beans requires molasses: the molasses provide calcium that literally holds the beans' walls together for the long cooking time! [Chang, K. (January 2, 2009). "At the Stove, a Dash of Science, a Pinch of Folklore." *New York Times*.]

[175] Williams, R.J.P. and J.J.R. Frausto da Silva (2008) "Evolution revisited by inorganic chemists." In *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning,* edited by John D. Barrow, Simon Conway Morris, Stephen J. Freeland, and Charles L. Harper, Jr., Cambridge Univ. Press, p. 468.

[176] Beyond calcium, nerves use small oxidized molecules to bridge the synapse gaps, which is also "virtually inevitable" because they must "bind relatively strongly and must not be substrates of main metabolism." [CoE p.372.] Calcium's use in bone is also explained by disproportionation. Calcium has always been rejected from the cell because of its powerful chemical ability, so it was able to be collected and mineralized on the outside of the organism as a hard shell (in this sense, calcium is cellular excrement). The key innovation occurred when this mineralization was moved to the inside of the organism, to protect the most important bundle of nerves, the spinal cord. [Soares, C. (2009) "Bone." *Scientific American*, 301 (3), p.91.] From there, it was a small step to create other mineralizations for limb structure, and for storage of calcium to use for signaling -- bones are buffers as well as load-bearers. Plants cannot use calcium for this because neither its carbonate (shells) nor its phosphate (bones) will precipitate in the plant's extracellular fluid; "Plants therefore precipitate silica and calcium oxalate and indeed some precipitate strontium or even barium sulfate." [CoE p.354] A chart of many minerals used as insoluble precipitates is given in *What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 31. Minor players such as iodine and selenium are also explained by this scheme (supported by their nearly coincident redox potentials). Their oxidized forms only happen late in the earth's age, and they are used only in animals for functions unique to animals; for example, humans use iodine for growth hormones. [CoE p.340.]

[177] Beryllium interferes with this signaling, so it is a good thing that the beryllium nucleus is unstable and there is not a lot of it in the environment.

[178] Table 8.21 CoE p.356. Also see Fig 9.3 CoE p.372 for a tree of increasing complexity of the pumps driving this underlying disproportionation, and how the sodium/potassium pump is similar to pumps for other metals (the family tree of disproportionation). For an explanation of Ca signaling relating its universality to an original endosymbiotic event, see Bothwell, J.H.F. and C.K.Y. Ng. (2005). "The Evolution of Ca^{2+} Signalling in Photosynthetic Eukaryotes." *New Phytologist*, 166 (1), 21-38.

energy capture and use in chemistry was to be secured within organization of a large, environment-sensitive organism."[179]

Sodium, potassium, and calcium holes make electric pulses, which make nerves, which make a brain,[180] which maps the environment to find food, reproduce, and start to speak, sing, and wonder at existence.[181] If relationship with others makes us human, then that gift is given through this sequence. G.K. Chesterton wrote, "If [man] was an ordinary product of biological growth, like any other beast or bird, then it is all the more extraordinary that he was not in the least like any other beast or bird. He seems rather more supernatural as a natural product than as a supernatural one."[182]

This brain, attuned to a musical universe, itself literally resonates with music: a 440 Hz tone will cause your auditory cortex to fire at 440 Hz.[183] Infant brains encode consonant chords that have simple integer ratios, but not dissonant tritones.[184] Most brains identify, not precise tones, but precise structures,

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[179] Figure 7.9 CoE p.304-5.

[180] Eyes are made from nerves with a light-absorbing pigment at one end. Eyes, too, appear to be composed of old parts reconfigured. Our light-sensing protein rhodopsin is also found in *Halobacter* bacteria. This protein has the pink pigment retinal at its heart, "a chemical similar to the carotene of carrots and formed by the oxidation of vitamin A. Retinal, the absorber of light in the retina of the mammalian eye, has a 4,000-million-year history." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 136.]

[181] A consequence of this new brain organ is that animals are born helpless and acquire mental maps of information as part of normal development. [CoE p.381.] The drive toward exploration is found even in video games such as the Legend of Zelda series! Aristotle said, "All men by nature desire to know." [From *Metaphysics,* quoted by Dallas Willard (2009). *Knowing Christ Today: Why We Can Trust Spiritual Knowledge*. HarperOne Publishers, p. 38.] The brain is characterized by this desire to know its environment and others. This large-brained speaking and singing human is a different class of creature. Taxonomically, a little lower than the angels? Chemically speaking, we have used our brains to access parts of the periodic table previously off-limits to nature.

[182] Before this quote, G.K. Chesterton points out that the first artist who drew pictures on a cave wall, or "reindeer man" in his terms, was a unique type: "When all is said, the main fact that the record of the reindeer man attests, along with all other records, is that the reindeer man could draw and the reindeer could not. If the reindeer man was as much an animal as the reindeer, it was all the more extraordinary that he could do what all the other animals could not." [Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press, Ch. 1.] "It is customary to insist that man resembles other creatures. Yes; and that very resemblance he alone can see. The fish does not trace the fish-bone pattern in the fowls of the air; or the elephant and the emu compare skeletons. Even in the sense in which man is at one with the universe it is an utterly lonely universality. The very sense that he is united with all things is enough to sunder him from all." [Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press, p.395.]

[183] Levitin, D. (2006). *This is Your Brain on Music: The Science of a Human Obsession.* Plume Books, p.29. This extends throughout creation, so we can see similar neurons oscillating in owls, for example (p.43).

[184] *Ibid*, p. 229, note that the tritone is an irrational ratio on p. 74. The overtone series is expected to be universal, see p. 44. Levitin also points out that this preference for tonal simplicity expands into certain kinds of surprise and

precisely tuned relationships among tones, a process that prepares the brain for language and therefore relationships with others.[185] Music wordlessly prepares the way for language, just like natural theology wordlessly prepares the way for revelation.[186] What began with the disproportionation of sodium and potassium inside a bubble billions of years earlier eventuated in a self-conscious organ that relates person to person, a set of cellular connections that can worship true or false gods. This resonates with the parable of the hidden seed, growing in secret for a long time before harvest, remaining hidden until its story is revealed.[187]

What the Chemical Songs Mean

This is a chemical story of creation. This story depends on universal chemical availabilities, solubilities, charges, and bonding properties of elements from carbon to copper. R.J.P. Williams writes, "Much though [Richard] Dawkins' image of the watchmaker who is blind may be useful in the description of species evolution, … we see that the overall activity of the watchmaker was constrained by the nature of changing chemicals and the thermodynamic equilibrium conditions of the environment. … Life was in a physical chemical tunnel and there was only one way to go."[188] Chemistry is a constraint that narrows the possibilities of where and how life can form until it reaches a point of "optimal use of all the components, energy, and material … ."[189] "… [I]t is not chance which drives evolution but a dominant thermodynamic drive towards equilibrium via energy degradation in sophisticated chemical pathways – organisms."[190]

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dissonance as the infant becomes an adult, with a special preference for the music learned at age 14. The brain detects harmonic overlap and "chunks" chords that physically go together, see p. 218.

[185] *Ibid*, p. 225 and 262. For a music teacher's very similar conclusions reached pedagogically, see Eskelin, G. (1994). *Lies My Music Teacher Told Me*. Stage 3 Publishing (Woodland Hills, CA), p. 44 and 53-55, 68.

[186] Like John the Baptist?

[187] It's like when, in *The Silver Chair* by C.S. Lewis, Eustace and Jill cannot see the message carved for them in the rock because they are inside the clefts that form its huge letters. Science gives us the perspective to see this message carved in the rock of the earth with chemical bonds. It also resonates with St. Paul's purpose: knowing Christ. We have a drive to truly know truth, to align brain-maps with reality.

[188] Williams, R.J.P. and J.J.R. Frausto da Silva (2003) "Evolution was Chemically Constrained." *J. Theo. Biol.* 220, 335.

[189] Williams, R.J.P. and J.J.R. Frausto da Silva (2008) "Evolution revisited by inorganic chemists." In *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning,* edited by John D. Barrow, Simon Conway Morris, Stephen J. Freeland, and Charles L. Harper, Jr., Cambridge Univ. Press, p.476.

[190] CoE p.131. One possible objection is that "correlation is not causation," but because chemical equilibrium is fast on the timescale of evolution, we can conclude that the chemical changes must have happened first: "David Krakauer, an evolutionary theorist at the Santa Fe Institute in New Mexico, says Williams and da Silva have simply

In this view the role of chance is constrained by the chemical elements. Stephen Jay Gould made the provocative statement that if the tape of life could be rewound, life would be completely different.[191] But Leigh Van Valen said, "Play the tape a few more times, though. We see similar melodic elements appearing in each, and the overall structure may be quite similar. … Look at the tape as a whole. It resembles in some ways a symphony, although its orchestration is internal and caused largely by the interactions of many melodic strands."[192] (Or, I would add, the interactions of atoms.) Darwin's tree of life is constrained under a solid roof of chemistry, bringing its branches together.[193] (Simon Conway Morris describes what these converged biological branches look like.) Species development does not take place in a vacuum; it is more like a boat carried down a river, with chemical availability and liquid flow defining the river.[194] Evolution is like a rubbing, coloring the thin, flowing paper of life to reveal the

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listed the chemical processes that coincided with each evolutionary transition, which does not prove that the chemistry caused the transitions. But Williams says that the environmental changes had to come first, because they occur faster than changes in biological systems." [Ananthaswamy, A. (January 20, 2003). "Chemistry guides evolution, claims theory." *New Scientist* website: accessed November 27, 2009 at http://www.newscientist.com/article/dn3267-chemistry-guides-evolution-claims-theory.html.]

[191] Granted, it may look very different, but biochemically, in the flowing medium of water, it will still turn light into chemical bonds, polymerizing and depolymerizing carbon, with the depolymerizers breathing in oxygen and breathing out carbon dioxide, because *this is the most efficient ultimate arrangement the periodic table allows*. Simon Conway Morris agrees that species may look very different but points out that their senses must interact with the same chemical environment, and therefore develop toward the same "islands of stability." Conway Morris lists examples of senses that actually start to look the same after a while, constrained by the physical parameters of the earth. Species start at very different points and end up converging on the same environment. [Conway-Morris, S. (2006). "Evolutionary Convergence." *Curr. Biol.,* 16(19), R826-7.] This prevalence of convergence may have caused confusion in which some scientists labeled a primate a "missing link" because of features shared with humans, when in fact it was more closely related to lemurs, and the shared features were examples of convergent evolution. [Erik R. Seiffert, Jonathan M. G. Perry, Elwyn L. Simons & Doug M. Boyer. (2009). "Convergent evolution of anthropoid-like adaptations in Eocene adapiform primates." 461, 1118-1121, doi:10.1038/nature08429.]

[192] McGrath, A. (2009). "The enigmas of evolutionary biology," *Gifford Lectures* No. 4, p.10.

[193] This suggests that senses converge into similar solutions for optimal processing of the environment. Does all life process energy using similar chemicals and similar pathways because those are in fact optimal (given availability)? Is this why we do not see new life emerging except from one point? We have to know more to answers these questions, careful to avoid the "Panglossian fallacy." One way to avoid this is to discuss optimal behavior at the broad "chemotype" level of cooperating ecosystems rather than that of competing individual species. The diverse forms of processing the environment include the following: "Snakes sense infrared radiation. Whales hear ultrasound. Bees detect the plane of polarization of visible light. Wasps see ultraviolet light patterns in flowers that look unpatterned to us. Dogs enjoy "ultrasmell." Sharks ferret out buried prey by detecting electrical potentials from the heartbeats of the hidden." [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 137.] Such optimal processing of the environment is characteristic of life and suggests convergence.

[194] If evolution is what makes the organism fit efficiently into the environment according to chemical rules, then we Christians do not need less evolution – we need *more,* because evolution is one of the ways God works.

solid chemistry underneath.[195] The conception of evolution as cosmic crapshoot explains speciation[196] but does not explain the sequence of reactivities and disproportionations that led to life. Dallas Willard wrote, "The origin of physical order cannot be explained by evolution. Evolution itself is an 'order' that … presupposes … a vast scale of order and existence within which alone it can occur."[197] Such physical order is expressed in the periodic table.

Life was constrained to follow this seven-song cycle, in a logical sequence of chemical development, as Williams and da Silva wrote, an "inevitable introduction of new, but dependent, chemotypes in an unavoidable chemical sequence."[198] "Probably, life was destined to happen because it is an effective (and efficient) way to degrade available energy."[199] Chemistry constrains biology and pulls it in the direction of ever-increasing entropy production and therefore ever-increasing oxidation, and therefore

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[195] This model of evolution is as a consequence predictive: One of the predictions of this chemical story is that organisms should exhibit "localized genetic variation dependent on novel chemicals forcing exposure of localized gene regions that then mutate most rapidly," [Williams, R.J.P. and J.J.R. Frausto da Silva (2008) "Evolution revisited by inorganic chemists." In *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning,* edited by John D. Barrow, Simon Conway Morris, Stephen J. Freeland, and Charles L. Harper, Jr., Cambridge Univ. Press, p.485.], which would be portions ready to kick evolution into overdrive when the chemical environment changes. [See also CoE p.301.] Charles Kingley in 1871 put it this way: "We knew of old that God was so wise that He could make all things: but, behold, He is so much wiser even than that, that He can make all things make themselves." [quoted by McGrath, A. (2009). "The enigmas of evolutionary biology," *Gifford Lectures* No. 4 p. 16.] "Shall the clay say to him who forms it, 'What are you making?' Or shall your handiwork say, 'He has no hands'?" (Isaiah 45:9 NKJV) I propose that God got his hands dirty molding this table.

[196] A role for randomness in the process is also musical, and our brains actually prefer music with some random contingency built in that surprises us: "Music is organized sound, but the organization has to involve some element of the unexpected or it is emotionally flat and robotic. Too much organization may technically still be music, but it would be music that no one wants to listen to." [Levitin, D. (2006). *This is Your Brain on Music: The Science of a Human Obsession.* Plume Books, p. 173.]

[197] Dallas Willard (2009). *Knowing Christ Today: Why We Can Trust Spiritual Knowledge*. HarperOne Publishers, p. 114.

[198] Williams, R.J.P. and J.J.R. Frausto da Silva. (2008). "Evolution revisited by inorganic chemists." In *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning,* edited by John D. Barrow, Simon Conway Morris, Stephen J. Freeland, and Charles L. Harper, Jr., Cambridge Univ. Press, p.475.

[199] *Ibid*, p.487.

ever-increasing sensing of the environment, communication within the self, and with others at last;[200] a sequence that provides life with a narrative drive.[201] Organisms sense and then know ever more of their environment, until they know themselves and others, and are ready to know God.[202]

The chemical and scriptural stories are both built on order and unfold over time.[203] In musical terms, this is a double fugue of two themes: one theme is the chemistry that leads to persons and the other is the revelation of Christ, relating those persons to a universe in which a crucified King is Lord of creation.

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INCREASE IN INFORMATION TRANSFER IN EVOLUTION

Organism	Information Transfer with Sensors
Prokaryotes	Food, light gradients, magnetic/gravitational fields
(a) Aerobes only	Oxygen gradient, CO/NO gradients
Eukaryotes	As above plus the following
(a) Single cells	Contact – Ca^{2+} gradient
(b) Multi-cell	Cell–cell connection by organic chemicals
(c) Nervous systems	Na^{+}/K^{+} gradient connection

Table 9.9 CoE p. 383

201 Entropy and oxidation are linked because the chemical cycles spin in the sunlight like a Crookes radiometer, entropy-poor light changing to entropy-rich heat, with green plant leaves acting as the black-white paddles, absorbing light and releasing it as heat or as kinetically stable biopolymers. Animals turn the paddles by seeking out and degrading plants and other animals, accelerating entropy production. [See CoE p.328.] Both our ecosystem and the radiometer are light-driven organized cycles. The chemical direction of the change must be toward increased entropy and increased oxidation. I cannot disprove alternate chemistries of life, within this periodic table or another; but any other chemical arrangements should provide a complete account for elements and energy, available in a state of flow, which places the burden of proof decidedly on the counterfactual. Recall that this natural theology does not assert or prove, but rather it suggests and aligns. Because of its basis in the quantitative aspects of chemistry, I prefer this interpretation to that promoted by Margulis and Sagan, which is based on the proposition that all organisms can choose their destiny (would this be biological existentialism? It is hard for me to see where this choice ultimately comes from – other than sheer randomness – in a deterministic, sealed universe. If a teleology leaves you with randomness is it still a teleology?). [*What is Life?* by Lynn Margulis and Dorion Sagan (1995). Simon and Schuster: New York. 182-4.]

202 Of course, then we mess it all up, but that requires a natural theology of sin, which is a different lecture. This actually has something to say about global warming. Life can indeed change its chemistry of the world for the short-term worse. Oxygen was originally a killing pollutant, and the world did eventually change. We are part of the world, and the chemicals that life ejects into the environment can change (and have changed) the world. [See CoE p.455.] Does this drive toward communication with others align with Samuel Taylor Coleridge's concept of "an inherent drive toward 'individuation'" driving all life to self-consciousness? [See Holmes, R. (2008). *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science*. Pantheon Books (Random House), p. 322.]

203 "The most important way that music differs from visual art is in how we track chord sequences in music over time. As tones unfold sequentially, they lead us – our brains and our minds – to make predictions about what will come next. These predictions are the essential part of musical expectations." [Levitin, D. (2006). *This is Your Brain on Music: The Science of a Human Obsession.* Plume Books, p.125.]

Creation is like music for those with ears to hear. Different elements dominate different geological eras like different instruments in a symphony, first hydrogen, then sulfur and iron, then oxygen and zinc, each coming forward in sequence, their electrons vibrating with unheard sound. The relationships of the elements give a sequence over time that unfolds like the relationships of notes in a sequence of chords. Gerald Eskelin wrote that Rameau's major/minor musical system "fit the physical acoustic facts of the nature of sound better than any previous musical system,"[204] later expanded upon by others including the scientist Hermann von Helmholtz[205] and the theologian Jeremy Begbie.[206] Like Rameau's "natural" musical system, Williams and da Silva's chemical sequence is tuned closely to the fundamentally ordered nature of the universe. The sequence is musical because the universe is musical. McGrath said, "A fundamental theme of a Christian doctrine of creation is that the world is ordered."[207] At the moment of creation the laws of physics ordered the periodic table which ordered the behavior of chemicals throughout history.[208] This aligns with the poetic books of Scripture praising God for constraining chaos. When Jesus stilled the sea he repeated his actions of billions of years earlier.[209] Who is this man, that even the winds and the sea obey him?

With all this in mind, we can retell the story:

In the beginning God created the heavens and the earth. … Then God said, "Let there be light"; and there was light. … Then God said, "Let there be a firmament in the midst of the waters, and let it ***divide*** the waters from the waters." … Then God said, "Let the waters under the heavens be gathered together into one place, and let the dry land appear"; and it was so. … Then God said, "Let the earth bring forth grass, the herb that yields seed, and the fruit tree that yields fruit according to its kind, whose seed is in itself, on the earth"; and it was so. … Then God said, "Let there be lights in the firmament of the heavens

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[204] Eskelin, G. (1994). *Lies My Music Teacher Told Me*. Stage 3 Publishing (Woodland Hills, CA), p.113.

[205] *Ibid*.

[206] In several places, including *Resounding Truth* (2007).

[207] McGrath, A.E. (2008). *The Open Secret: A New Vision for Natural Theology.* Wiley-Blackwell. P. 293.

[208] The universe is ordered such that it's not a question of *whether* you believe in something infinite, but *which* infinity you believe in: either an infinite personality as Creator; or an infinite number of impersonal universes that accidentally form personalities, such as proposed by Sir Martin Rees in *Just Six Numbers.* (You can even believe in both, but believing in neither is not a current option.)

[209] Scriptural passages about the constraint of chaos align, with the sea as the primary example of chaos: In the book of Job, the Lord asks, "Where were you when I laid the foundations of the earth? When I fixed My limit for it, And set bars and doors; … When I said, "This far you may come, but no farther, And here your proud waves must stop!' (Job 33:4a,10-11) The chaotic monsters in the last chapters of Job invite reflection: according to these chapters, they may be constrained but they are clearly not domesticated or neutered. (John Schneider. (2009). "Genetic Science and Christianity's Story of Human Origins: An Aesthetic 'Supra-Lapsarianism.'" American Scientific Affiliation National Meeting, Baylor U., www.asa3.org.)

… to give light on the earth"; and it was so. God had made[210] two great lights: the greater light to rule the day, and the lesser light to rule the night. He made the stars also. … Then God said, "Let the waters abound with an abundance of living creatures, and let birds fly above the earth across the face of the firmament of the heavens." … Then God said, "Let the earth bring forth the living creature according to its kind: cattle and creeping thing and beast of the earth, *each* according to its kind"; and it was so. … Then God said, "Let Us make man in Our image, according to Our likeness; … ." So God created man in His own image.

Tuning the Two Stories

To align the scriptural story with the chemical story we must open a conversation between them.[211] Holding that the stories are antithetical is incompatible with the orthodox theology of a good creation and one truth. Gould walled off science and faith as "separate but equal" non-overlapping magisteria,[212] prohibiting cross-talk and provoking constant border disputes. This is incompatible with Paul's images of Jesus abolishing such walls.[213] Because there is one creator of one truth to know, fruitful interchange must be possible. The chemical story is a distinct creation story from a unique viewpoint, providing

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[210] Rodney J. Whitefield. 2009. "The Fourth Creative 'Day' of Genesis: Answering the Questions about the Sun and the Moon." American Scientific Affiliation National Meeting, Baylor U., www.asa3.org.) I use it here not because I am sure this is correct, but because it makes for a simpler alignment.

[211] First establish that they are stories. What happened when this Creator walked on Earth is given as four true gospel stories in tension, each a narrative with plot and climax, not a collection of disconnected sayings. (In fact, the only "gospel" that is such a collection is the Gospel of Thomas, which is a strong clue that it is not a gospel at all.) This Creator-on-earth talked in terms of parable stories, many drawing conclusions about God from the natural world. Scripture is a story that resonates with nature, and is a form of evidence. "Scripture is not an unchallengeable set of propositions demanding unquestioning assent, but it is *evidence*, the record of foundational spiritual experience, the laboratory notebooks of gifted observers of God's ways with men and women." [Polkinghorne, J. (2000). *Faith, Science, and Understanding*. Yale University Press, p.37] John Haught points out, "If design ruled everything, as today's 'intelligent design' advocates would prefer, necessity and rigidity would have locked life into eternal stasis – death, in other words. There would be no story to tell. … If nature is to be a rich narrative, we must remark at how fortunate it is that adaptation and 'design' are not comfortably complete."(Haught, John. (2008). "Purpose in Nature: On the Possibility of a Theology of Evolution." In *The Deep Structure of Biology: Is Convergence Sufficiently Ubiquitous to Give a Directional Signal?* Edited by Simon Conway-Morris, Templeton Press, pp.229-30.) John Henry Newman said, "The heart is commonly reached, not through the reason, but through the imagination, by means of direct impressions, by the testimony of facts and events, by history, by description." In short, by story. There must be something to this narrative method we call story.

[212] Gould, S.J. (1999). *Rocks of Ages: Science and Religion in the Fullness of Life*. Ballantine Books.

[213] Galatians 2:11-22.

images and colors that fill in the ancient scriptural story.[214] Both stories are true; both stories are to be relied upon and "can be known through fair inquiry."[215] Greg Wolfe's 2003 Weter Lecture proposed that a third faculty, imagination, complements the two faculties of faith and reason.[216] Chemist Humphrey Davy wrote "Imagination, as well as the reason, is necessary to perfection in the philosophic mind."[217] To set up the conversation, interpret "imagination" literally, as a series of *images* in a story that can reconcile multiple stories, even mending the rifts between. I propose a projection of scientific images onto the black-and-white words of the Book, like sunlight coming through stained glass, painting colors inside a cathedral, with eternal words carved in stone: "In the beginning God created the heavens and the earth."

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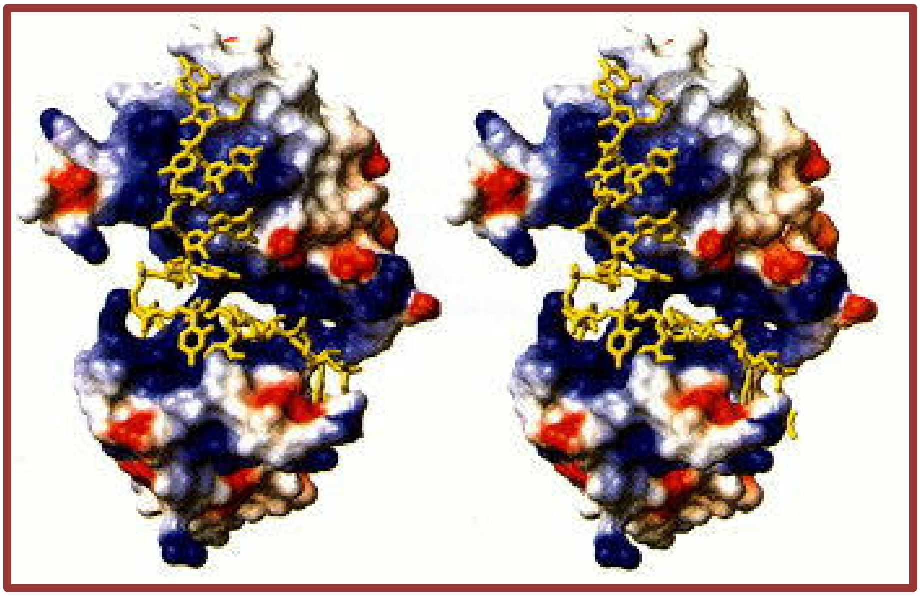
[214] This action of filling in uses the tool of metaphor. Psalm 93: 3-5 says "The sea is his, for he made it, and his hands formed the dry land." But if you're not thinking of two big hands molding Mt. Rainier, we're clearly using some kind of metaphor. (If you are thinking of that, feel free to check for thumbprints.) All forms of creationists and evolutionists use metaphors, the question is the complexity and timescale of the image used. The claim of ownership in Psalm 93 stands up whether the hands touched the dry land directly or fashioned the periodic table that caused volcanic activity and glacial erosion to sculpt the ravines that are on the back of the Washington state quarter. However extensive, it is nonetheless God's.

[215] For what this means for the scriptural story, see Dallas Willard (2009). *Knowing Christ Today: Why We Can Trust Spiritual Knowledge*. HarperOne Publishers, p. 203.

[216] [2003 Weter Lecture.] In his 1981 Weter Lecture, Gene Lemcio said, "Perhaps what we need is not so much the integration of faith and learning as a conversation between them." [1981 Weter Lecture] Denis Noble wrote "Different, even competing, metaphors can illuminate different aspects of the same situation, each of which may be correct even though the metaphors themselves may be incompatible." [Noble, D. (2006). *Music of Life: Biology Beyond the Genome.* Oxford Univ. Press, p.15.]

[217] Holmes, R. (2008). *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science*. Pantheon Books (Random House), p. 276. Davy was also a poet and wrote a striking verse to the Creator of all things – "These are but engines of the eternal will, the One intelligence … Without whose power, the whole of mortal things // Were dull, inert, an unharmonious band." quoted *ibid*. p. 300. On another instance Davy wrote "The object of Chemical Philosophy is to ascertain the causes of all phenomena of this kind, and to discover the laws by which they are governed. The ends of this branch of knowledge are the applications of natural substances to new uses, for increasing the comforts and enjoyments of man; and for the demonstrating of the order, harmony and intelligent design of the system of the earth." *Ibid*. p. 345.



A picture for bringing two spheres together comes from biochemistry. Journal articles represent a complex protein structure with a wall-eye stereogram: two slightly different views for the left and right eyes. As you cross your eyes to focus on a point beyond, the two images blur, then converge to a clear three-dimensional image.[218] Others cannot do this for you. To see in 3-D you must practice bringing the images together. With stories, imagination can provide the overlap, with discipline, to see differently, without damaging either story. With this metaphor, the fact that the stories are different is not a problem. They must be different to give a three-dimensional story. If they were identical, their combination would be identical and flat. Two-fold vision cuts both ways: it sees a big picture by faith beyond mere mechanism, and it sets scripture as the primary story but allows other stories to color the words.

The superposition of stories that is two-fold vision can be thought of musically as overlapping chord sequences from multiple instruments. Jeremy Begbie has noted how the superposition of notes in a chord is like the superposition of persons in the Trinity.[219] Like notes in a chord, the two stories in two-fold vision need only be tuned, not identical, to resonate and emerge as something more.[220] From both stories, we know that creation began, then took time, with multiple stages. The faith story and the

[218] "Magic Eye" images work the same way except that they deliberately hide the left- and right-eye images in static. Figure 17.19 caption [from Scott F. Gilbert (2000). *Chromosomal Sex Determination in Drosophila,* Chapter 17 (NCBI Bookself: http://www.ncbi.nlm.nih.gov/sites/entrez?db=Books)]: "Stereogram showing binding of tra pre-mRNA by the cleft of the Sxl protein. The bound 12-nucleotide RNA (GUUGUUUUUUUU) is shown in yellow. The strongly positive regions are shown in blue, while the scattered negative regions are in red. It is worth crossing your eyes to get the three-dimensional effect. (From Handa et al. 1999; stereogram courtesy of S. Yokoyama.)"

[219] Begbie, J. (2008). "On the 'Naturalness' of Natural Theology: Learning from Rameau and Rousseau on Music." Lecture at Beyond Paley conference, Oxford, UK.

[220] Chemical bonds delocalizing and blending into each other according to precise rules is also called "resonance." If you have drawn a benzene ring, you also know it is equivalent to draw it two different ways, and the bonds are smeared not by fuzzy feeling but by mathematically precise rules. Language itself is a clue. If the same word resonance describes both the resonance of music and the resonance of chemistry, then the same word creation may describe both the creation of chemistry and the creation of Genesis.

science story differ in the order of some stages and the length of time. Then again, even the science story must be told out of order for clarity: oxygen consumption and production probably actually preceded the nickel-and-methane world, but the bottom line is that we only know photosynthesis started within 800 million years, long before it changed the world.[221]

The two-fold vision metaphor is incomplete; the two side by side images appear equivalent, but Christians are pre-committed to scripture's side – in musical terms, Genesis sets the key.[222] Because Genesis was written in another time's language with another time's science, we may fill its statements with images found by scientific tools. By giving scripture primacy but interpreting it with humility, we can maintain "two-fold vision" without being double-minded. The knowledge of God as creator comes first, whichever mechanism of creation we discover. He is the carpenter who built the periodic table.[223] The crucial testimony of scripture is that God gives origin and direction to the universe. The chemical creation story matches and expands that theology, illuminating its mechanism and order.[224]

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[221] Maybe 3.2 to 2.4 billion years ago. [Castelvecchi, D., (2009) "Photosynthesis." *Scientific American*, 301 (3), 89. Also see Leslie, M. (2009). "On the Origin of Photosynthesis." *Science* 323, 1286-7.]

[222] Another way to state the primacy of faith is to rework the Jerusalem-Athens metaphor of the past, as Aaron Hebberd does in his review of John Mark Reynolds' *When Athens Met Jerusalem*: "Reynolds brings this to a head when he calls for the perspective of deeming Jerusalem-Athens as two districts of the same city rather than two cities. Again, I would rework the metaphor to be more like 'Jerusalem' as the city and 'Athens' as the Home Depot. While 'Athens' has given us the tools to think in a clearer and more methodical manner, the veritable content of 'Jerusalem' is well beyond comparison." (Review published in *Christian Scholar's Review*, XXXIX:1 (Fall 2009) p.134.) Another analogy is that of the journey of the Magi in Matthew: natural theology/astronomy is adequate to get the Magi to Jeruselem, but to get to Bethlehem revelation from scripture is needed.

[223] Mechanism does not replace Scripture because all mechanism is metaphor on some level, and because Scripture is real we simply may not replace Scripture with metaphor: for example, to reduce the historic nature of Jesus and the physical resurrection to metaphor would be a Gnostic betrayal of the Scriptural story. Rather, for the resurrection, as John Updike says, "Let us not mock God with metaphor, analogy, sidestepping transcendence; … let us walk through the door. … And if we will have an angel at the tomb, make it a real angel, … Let us not seek to make it less monstrous, for our own convenience, … ." ["Seven Stanzas at Easter" from *Telephone Poles and Other Poems* by John Updike.]

[224] Also, two-fold vision is found in sources like Augustine of Hippo, so it predates and does not merely accommodate the scientific method. Alister McGrath has proposed that Augustine not only correctly surmised that the world and time itself were created from nothing, but also that there were *rationes seminales*, "seminal reasons," only potentially existing and hidden in the earth to emerge after the original moment of creation [McGrath, A. (2009). "Conclusion: clues to the meaning of the universe?," *Gifford Lectures* No. 6, p. 9-14.] Such seminal reasons are implied in the columns of the periodic table. The theology of resurrection suggests that our physical bodies are a "seminal reason" to be planted in death and raised to eternal life. Augustine and modern science disagree on the notion of fixity of biological forms, and I think this is a superficial disagreement because the forms that have relevance for ordinary human life spans are fixed. "A classic doctrine of creation resonates strongly with both the notion of a "Big Bang" and biological evolution. There is no accommodation here; simply the

On the other hand, you can't get modern science from a reading of scripture no matter how close; natural theology aligns with but does not prove or produce science. The Bible consistently describes the world through the human senses; when science looks closer, it can contradict the senses, surprising us like when music suddenly modulates or skips away from the tonic. The sensory language the Bible uses does not anticipate modern science; there is no hidden "Bible Code" of science.[225] I conclude that God chose not to impose 21st-century cosmology on the text (presumably nomadic life was hard enough without astrophysics). God spoke words Moses understood into the world Moses knew. [226] I conclude God chose to prophesy about Christ Himself, not the mechanism of creation, which he left for us to find.[227] As for miracles, we know through testimony and history that God chose to physically resurrect

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observation of consonance between Augustine's position and what is currently accepted." [*ibid* p. 16.] Martin Rees quotes Augustine: "The universe was brought into being in a less than fully formed state, but was gifted with the capacity to transform itself from unformed matter into a truly marvelous array of structure and life forms." [Martin Rees (2000). *Just Six Numbers: The Deep Forces That Shape the Universe*. Basic Books (New York), p. 103.]

[225] The idea that ancient Israelites received a "cheat sheet" of prescient knowledge thousands of years before the scientific truth was discovered is a bit like the plot of *Back to the Future II* in which a character in the past uses knowledge from the future for profit: because the scientific knowledge would eventually provide economic advantage the Israelites could profit from such knowledge independently of relationship with God! (Is "scientific concordism" therefore a Faustian bargain?) The point of prophecy is not to give you winning lottery numbers ahead of time. We must conclude that these things do not matter to the heart of what it means to be the people of God, just as dietary laws did not matter to Gentiles in Paul's day. From the language they used, the Bible's authors operated with the reasonable assumption WYSIWYG ("What You See is What You Get") [Seeley, Paul H. (2009). "Does the Bible Use Phenomenal Language?" ASA National Meeting, Baylor University.]. Revelation apparently did not extend to the astronomical discoveries of the past few hundred years. If this is so, who are we to say to the potter, "What are you doing?" or "Why didn't you make Scripture reflect the true but hidden physical nature of the universe?"

[226] Hence, everything reproduces "after its kind" because that is true on the human observer's time scale. [See Denis O. Lamoureux, (2009) "The Sin-Death Problem: Toward an Evolutionary Creationist Solution." ASA National Meeting, Baylor University.] The biggest conflict between the two stories is timespan. Seven days is one thing, 13.7 billion years quite another. Genesis has linear, evenly paced unfolding of forms, but chemistry and human culture both unfold with exponential complexity. Scripture contains clues that its strict mathematical chronology is not an absolute article of faith. If Genesis 1 was written by Moses, then the same Moses (or someone wishing to be like him!) wrote Psalm 90, saying "For a thousand years in Your sight are like yesterday when it is past, and like a watch in the night," [Psalm 90:4] proposing alternatives to linear time. Perhaps creation was perceived by the author in seven days, or the days confront petty tribal gods, or the days give a liturgical structure to the seven-day week, with the practical upshot being the need to take a day for rest, just as God did. (In fact, my suspicion is that the "or"s in the last sentence should become "and"s!) It is self-defeating to argue for a 168-hour creation week if you yourself don't take a day off. If the concept of continual creation seems a problem, then turn to John's gospel, where Jesus tells us "my Father is always at work to this very day." [John 5:17]

[227] Paul Seeley discussed how the authors of the Bible used language that indicated they truly believed that, for example, the sun entered the underworld as it set each night: "If biblical inerrancy, or biblical inspiration perhaps we should say, is defined in a rigidly rationalistic manner, so that it cannot make a false statement about science,

Christ Himself -- this ***new*** creation event is the tonal center of history.[228] Currently the continuity of creation suggests God chose ***not*** to pepper the past with prehistorical biological miracles. The scientific perspective, standing on the shoulders of giants, shows the animal "kinds" described in Genesis evolving, perhaps in surprising sequence, yet still ***ordered and good***. It is also good that God let us understand His creation mechanism through the consistent chemistry of the periodic table; He didn't have to. Let us translate cosmologies as well as languages,[229] without modifying the revealed ***theology*** of creation that Scripture relates. Let the Spirit speak through the Hebrew words into our scientific context: after all, the creation story was written for us, not us for the creation story.

The term "two-fold vision" is William Blake's, who also prayed, "May God us keep / from single vision and Newton's sleep."[230] The overlap of and conversation between spheres is a constant theme of past Weter Lectures.[231] Overlap is seen in C.S. Lewis's comment that the medievals knew "better than some know now, that human life is not simple. They were able to think of two things at once."[232] Lewis scholar

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even when it was not God's intention to teach science, then the solid sky and literally moving sun which we find in the Bible must either be taken out of context and rationalized away as phenomenal language, or interpreted in context and recognized as evidence that the Bible is not absolutely inerrant -- that is, inerrant with regard to all of its statements of science. If on the other hand, Biblical inspiration is defined biblically, so that the teaching of Jesus that the Old Testament divorce laws involving a concession to sinfulness is accepted, then I can see no reason why the Old Testament cannot contain concessions to the science of the times. This would mean that scientific matters like the nature of the sky or the literal movement of the sun can be accepted as divine accommodations which leave the intended message of God inerrant and the Bible can still be defined as inerrant. I like to use the phrase inerrant for the purpose for which it was written." [(2009). "Does the Bible Use Phenomenal Language?" ASA National Meeting, Baylor University.]

[228] The Resurrection itself only happened once (so far) and is therefore inaccessible to science. It effects may be examined but not the event itself. Unique events by definition cannot be repeated in a controlled setting! (This is also a problem for scientists making life decisions, such as whom to marry or which job to take. Because time is unidirectional, such decisions cannot be made repeatedly under controlled conditions. When the scientist makes such a decision, she must take a kind of "leap of faith," trusting intuitions but not absolutely knowing the future.)

[229] We already do this automatically with the words "under heaven" and "pillars of the Earth" when Scripture is read.

[230] Blake, W. "Letter to Thomas Butts."

[231] And in terms of the slightly different overlap of the spheres of science and art, Samuel Taylor "Coleridge did not accept any contradiction between the two modes of vision. … Coleridge accepted that the rainbow was produced by refraction through the 'hail-mist,' but also that its paradoxical effect on *the observer* of beautiful steadiness amidst terrifying chaos had a powerful psychological and poetic symbolism." [Holmes, R. (2008). *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science*. Pantheon Books (Random House), p. 321.]

[232] Lewis, C.S. (1936). *The Allegory of Love*, p. 173. Likewise, 'When a Russian cosmonaut claimed not to have found evidence of God in outer space, [C.S.] Lewis's response was, "Much depends on the seeing eye."' [Ward, M. (2008)

Michael Ward continues, "There is a divine mandate for double and treble vision in the three-fold nature of God, the two natures of Christ, and in the various significations of His creation itself."[233] The overlap of different spheres is a major element in N.T. Wright's scholarship, whether spheres of heaven and earth, or of the spiritual and the material.[234] The paradoxes of different spheres of knowledge are like the paradox of the Trinity; the eye must learn to see simultaneously without full resolution.[235] This Creator makes things, does things, has real effects on real history, and yet is never caught from below. He is not a tame lion.[236]

Planet Narnia: The Seven Heavens in the Imagination of C.S. Lewis. Oxford Univ. Press, p. 243; quoting CSL in "The Seeing Eye" Essay Collection p. 61.]

[233] Ward, M. (2008) *Planet Narnia: The Seven Heavens in the Imagination of C.S. Lewis.* Oxford Univ. Press, p. 148. Grayson Capp in his 1982 Weter Lecture pointed out that John Wesley saw flowing gradients throughout nature, in, for example, the similarities between humans and apes.

[234] He said, "When we put these questions into yesterday's frameworks, we put them into frameworks which say that things must be either spiritual or material but can't be both. So we oscillate between a pietism which really has nothing much to say to the real issues of the world, or a merely political theology which forgets that Christianity is all about the love of God being poured out in our hearts through the Holy Spirit that's been given to us. How do you hold that together? The good news is the New Testament writers hold it together. The early apostles and those who came after them in the succeeding generations held it together, and it cost them dear. Because when you say Jesus is Lord with the implication that Caesar is not, Caesar is not going to enjoy this." [Wright, N.T. (June 10, 2009) "Jesus and Tomorrow's World," audio lecture stored at ntwrightpage.org.]

[235] This conversation may be difficult. One psychological study found an "automatic opposition" between the explanatory stories of God and science [(2009) *Journal of Experimental Social Psychology*, 45, (1), P. 238-241]. The "flesh" doesn't want to overlap spheres; it says the spheres must be kept separate or subconsciously subsumed: the mistake of Spinoza is that God is really all-Earth/no-heaven, and the mistake of the Gnostics is that God is really all-Heaven/no-Earth, but Christians overlap the spheres when we pray "Your Kingdom come on Earth ... as it is in Heaven." (Some Western churches pause between Kingdom come and on Earth, but if you are reciting the prayer in Kenya you will need to put the pause differently to stay in tune with everyone else. "An English bishop visiting Kenya noted how, 'without a pause at the end of the line after "be done," the people prayed "Thy will be done on earth – as it is in Heaven."' He 'speculated that that was because Kenyans lived closer to the soil than did Britons, who, not seeing the connection between God and the environment, leave an uncomprehending between God's will and the earth on which it is to be done." [Jenkins, P. (2006). *The New Faces of Christianity: Believing the Bible in the Global South*. Oxford Univ. Press, p. 63.]

[236] In the Wellcome Center in London, I came across an art installation by chance that is a scaffold in the shape of a periodic table with random items placed inside. The periodic table is the scaffold of the world, and the items that spring from it are not random but make chemical sense. The periodic table is like a chain-link fence at the bottom of the ocean, upon which a coral can grow and branch out with a certain constrained freedom – but it will always maintain the shape of the underlying scaffold. How this freedom relates to the incompleteness and the suffering of the creation itself is another topic for another lecture, but I will constrain myself to state here that a natural theology seen through Christian spectacles must be Trinitarian, and McGrath states that "A Trinitarian engagement with nature is already marked with the sign of the cross, and is thus especially attentive to the problem of suffering

Conclusion: Reading the Music

Knowing both stories, one hears the Bible anew. God is a billion times more patient than we had dreamed, and all the more ingenious to hide life in a handful of elements.[237] He is more the mind-blowingly transcendent other, alien even to time itself, making life to spring up and make itself to give Him glory. He is also more immanent, holding all things together[238] in the pushings and pullings of protons and electrons, fashioning a universe that unfolds to accomplish his purposes, personalities in His image. This aligns with Trinitarian theology, because music and communication emerge from creation and therefore relationship is built into creation as in God. Moreover, if oxygen was transformed from toxin to tent-peg of life, how else can God transform waste and pollution into something good, to his glory?[239] Like Paul in Acts 17, have confidence in the testimony of organized creation: we are all creatures dependent on the periodic table and related from a single point.[240] This story gives in G.K. Chesterton's phrase the "palpable impression that the universe after all has one origin and one aim; and because it has an aim must have an author."[241]

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in nature. … [It] allows us to see nature with both eyes, giving a rich and truthful account of what is seen … ." [McGrath, A. (2009). "Natural theology and the quest for meaning," *Gifford Lectures* No. 5, p8,10.]

[237] The penultimate "Easter egg"?

[238] Colossians 1:17.

[239] If old creation's "let there be light" was a Big Bang explosion, then the beginning of Acts makes sense as a similar explosion of new creation: the church exploded from Jerusalem, then through Judea, Samaria, and the uttermost parts of the Earth. On Pentecost tongues of fire separated out from a point, as star had separated from star. Even to the Tower of Babel, which can be interpreted as an act of creation of diversity as well as dispersal! Stanley Hauerwas commented, "From Yoder's perspective too often God's destruction of the tower of Babel is interpreted as punishment. But such a reading, according to Yoder, fails to appreciate that the first meaning of Babel was the effort of a human community to absolutize itself. Those who built the tower were attempting to resist God's will that there be a diversity of cultures. … God's scattering of the people from Babel was therefore a benevolent act. At least that is the way Paul saw what happened at Babel as reported by Luke in the Book of Acts (14:16ff; 17:26f). … "Thus the 'confusion of tongues' is not a punishment or a tragedy but the gift of new beginnings, liberation from a blind alley."" [Hauerwas, S. (2008). *The State of the University: Academic Knowledges and the Knowledge of God.* Wiley-Blackwell p. 70-71 quoting Yoder in *For the Nations* p. 63.]

[240] In Chesterton's phrase "the idea of the fatherhood that makes the whole world one." [Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press p.227.]

[241] Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press Man p.294. Note that Chesterton, like Augustine, predated the discovery of the Big Bang and would never be accused of accommodation. Chesterson wrote, "[Man] sees a green architecture [around him] that builds itself without visible hands; but which builds itself into a very exact plan or pattern, like a design already drawn in the air by an invisible finger. … There was someone else, some strange and unseen being, … a mysterious benefactor who had been

A good, knowable Creation implies the same for its Creator, who revelation tells us stepped into history as the true and crucified King, who can be known today.[242] Creation is a tuneful story inviting us to harmonize,[243] but its chords can be complex and dissonant to our ears. Resolution is heard in the echo of an empty tomb. Music is a cycle of tension and release,[244] and if creation is musical then we trust the tension and injustice we hear today will be resolved. We step into a symphony with Christ as the summation.[245] The knowledge that is faith and the tuning of our hearts to the Spirit keep us in the flow of the true song of the universe. We are constrained by the key of the tune and the laws of physics, yet we are free to improvise. The chemical story of creation repeats the message of Genesis: that we are dependent creations and ordered reflections of God's glory.

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before them and built up the woods and hills for their coming, and had kindled the sunrise against their rising, as a servant kindles a fire." [Chesteron, G.K. (1925). *The Everlasting Man.* From *Collected Works of G.K. Chesterton Vol. 3*, Ignatius Press, p.396.]

[242] See Dallas Willard's *Knowing Christ Today*.

[243] And in doing so bear witness "to the non-godforsakenness of the world even under the conditions of sin," in Hauerwas's phrase. [Hauerwas, S. (2008). *The State of the University: Academic Knowledges and the Knowledge of God.* Wiley-Blackwell.]

[244] Levitin, D. (2006). *This is Your Brain on Music: The Science of a Human Obsession.* Plume Books, p.14.

[245] N.T. Wright. (1989). "How can the Bible be authoritative?" *Vox Evangelica*, 1991, 21, 7–32, footnote 5.

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